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Analysis of Reflectarrays with Design and Fabrication of Some Enhanced Prototypes

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Main Contents

- Introduction

- Enhanced Sub-Wavelength Element

- Some Enhanced Prototypes Reflectarrays

- Conclusion and Future works

Abstract

In this presentation, various enhanced reflectarray (RA) antennas are analyzed, designed and fabricated. Initially, an enhanced RA built of elements with reduced reflection phase sensitivity is presented. The proposed unit element is composed of concentric, multi-resonance circular-rings with variable sizes. By changing the outer and inner radius of the interior ring in the opposite directions, a reduction in the phase sensitivity to manufacturing inaccuracy is achieved without extra contribution to the 360° phase range and decreasing the losses in the unit element is achieved. In addition, the margin between normal and oblique incidence of phase response for angles up to 40°, is smaller than 10°, which results in a high-efficiency, wideband performance. Measurement results show a maximum gain of 26.4 dBi at 10 GHz, aperture efficiency of 44.27%, and 16.3% 1 dB gain bandwidth. In order to improve the bandwidth of antenna, the phase constant ($\psi_\circ$) value at the RA aperture is gradually tuned and optimized. The designed antenna with $\psi_\circ$ = -125° has a peak gain 26.6 dBi at 10.2 GHz, aperture efficiency of 44.56%, and the 1 dB gain bandwidth is about 23.3% (9.67-12 GHz). In comparison with the conventional antenna ($\psi_\circ$ = 0°), the 1dB gain bandwidth shows a 43% improvement without no additional cost. Finally, an RA antenna with a novel subwavelength frequency selective surface (FSS) is introduced as a ground plane. The triple-connected C-shaped resonator as FSS is used in each unit element instead of the ground plane, so that it is reflective in the frequency range of 9.42-12.55 GHz and is transparent outside the working frequency band of the antenna. The proposed FSS-backed RA has a peak gain of 26.26 dBi at 10 GHz with a 42.87% aperture efficiency and 15.4% 1 dB gain bandwidth. The gain of RA with the FSS ground plane is 0.3 dB lower than the RA with a solid-metal ground plane, while their 1 dB gain bandwidth is almost equal. Additionally, the radar cross section (RCS) and cross-polarization levels of the presented FSS-backed RA antenna are considerably improved compared to solid ground RA within the operational bandwidth.

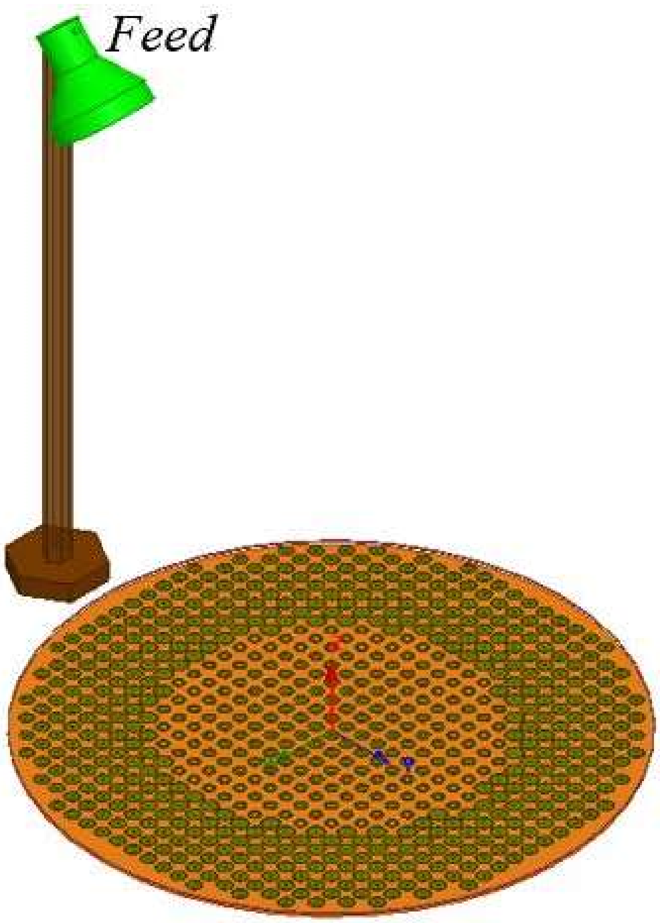
Keywords: Antenna, concentric rings, frequency selective surface, reflectarray, sub-wavelength, wideband.

Biography

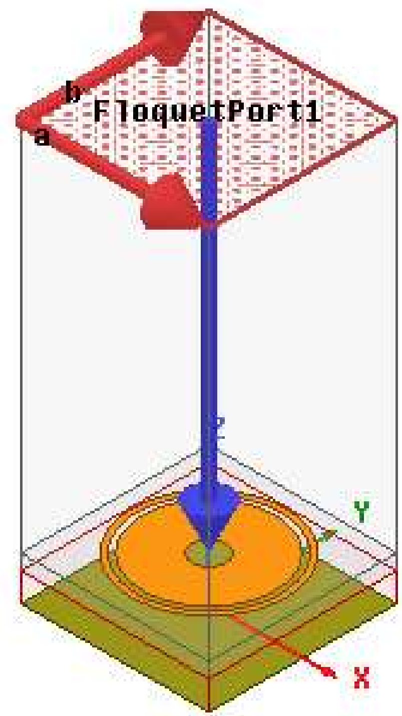
Bahman Mohammadi received the B.S. degree in Electrical Engineering-Telecommunication from Tabriz University, Tabriz, Iran, in 2011 and M.Sc. degree in Electrical Engineering-Microwave, Antenna and Propagation from Urmia University, Urmia, Iran, in 2013 (1 honor or award), at the Electrical Engineering, Urmia University, Urmia, Iran. He is currently with Northwest Antenna and Microwave Research Laboratory (NAMRL) at Urmia University as a Ph.D. student since October 2014. He has coauthored more than 70 journal and conference papers. His research interests include Periodic Structures, Filters, MIMO Antennas, Metamaterial and Optimization.

Mr. Mohammadi is a student member of the IEEE Antennas and Propagation Society (IEEE APS), the IEEE Microwave Theory and Techniques Society (IEEE MTT-S), Applied Computational Electromagnetics Society Journal (ACES) and Iranian Scientific Society of Engineering Electromagnetics (ISSEEM). He is the chair of the IEEE Student Branch in Urmia University from 2017 to 2019. He was recipient the best(1st) paper award in 9th International Symposium on Telecommunications (IST2018) at antenna track, one of the best reviewer of International Journal of Electronics and Communications (AEUE) journal in 2018. He serves as a reviewer for the journals IET Microw. Antennas Propag, Applied Computational Electromagnetics Society Journal (ACES), Journal of Electromagnetic Waves and Applications (JEMWA), Wireless Personal Communications, IEEE Transactions on Industrial Electronics, International Journal of Electronics and Communications (AEUE), Electronics Letters (ELL), IEEE Antennas and Wireless Propagation Letters (AWPL), Frequenz, Microwave and Optical Technology Letters.

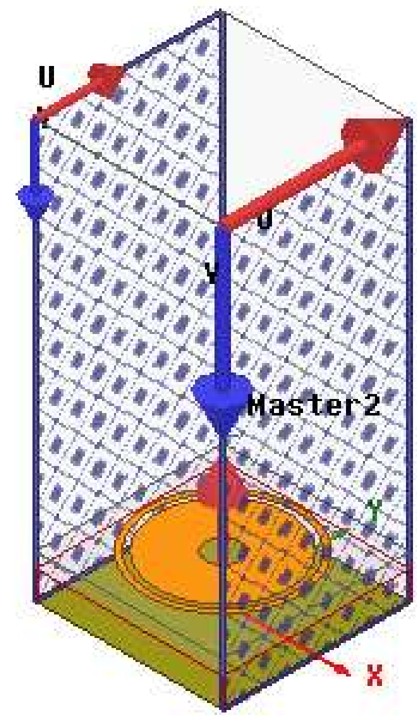
Introduction on Reflectarray Antennas



Antenna Aperture

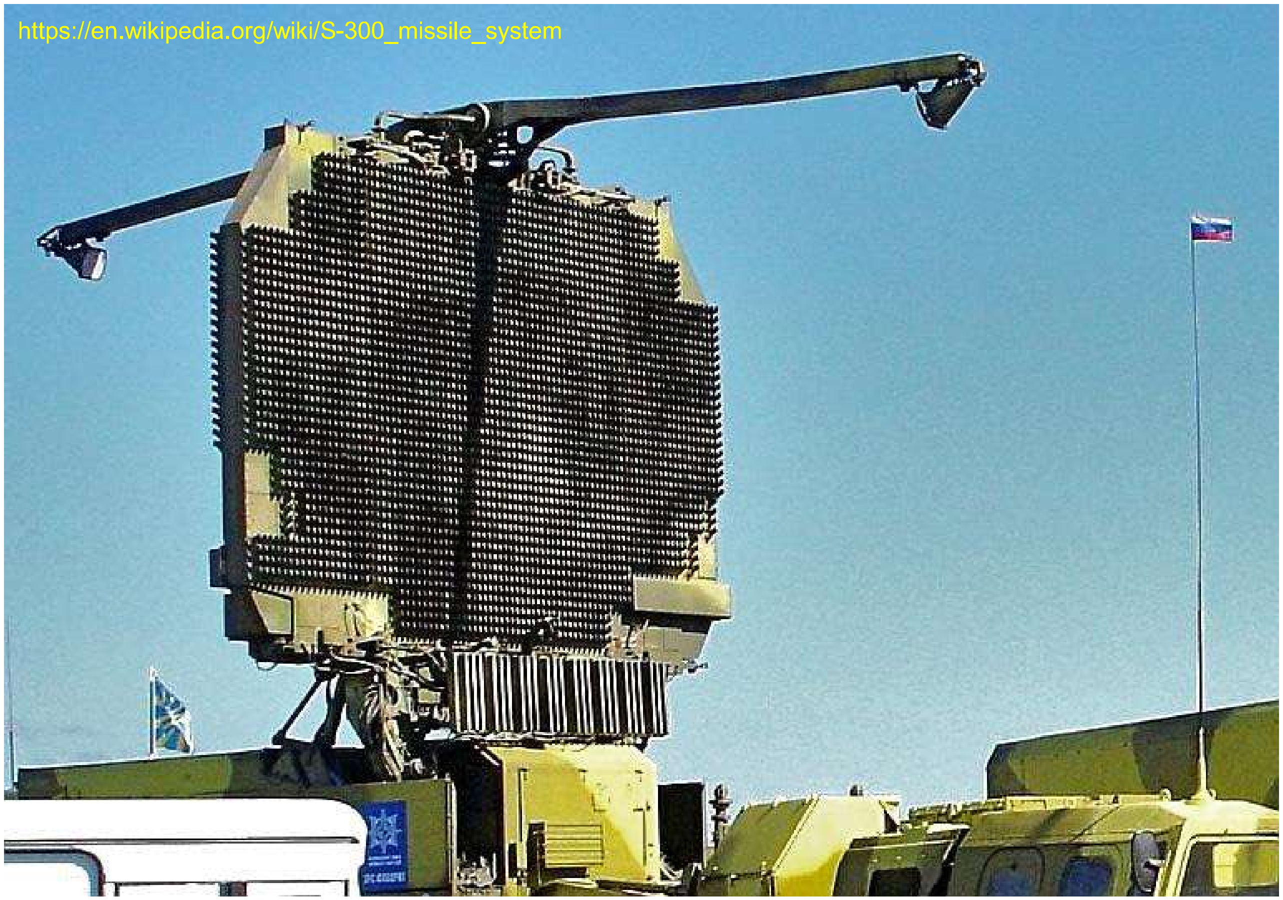


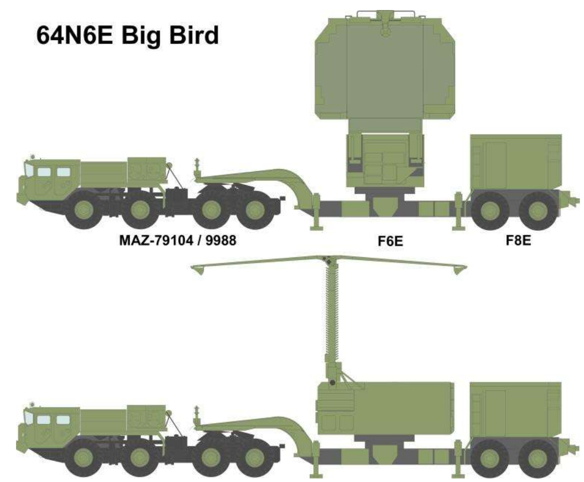
Floquet Port Excitation



Periodic Boundary Condition

Back to Back Two Reflectarray Antennas

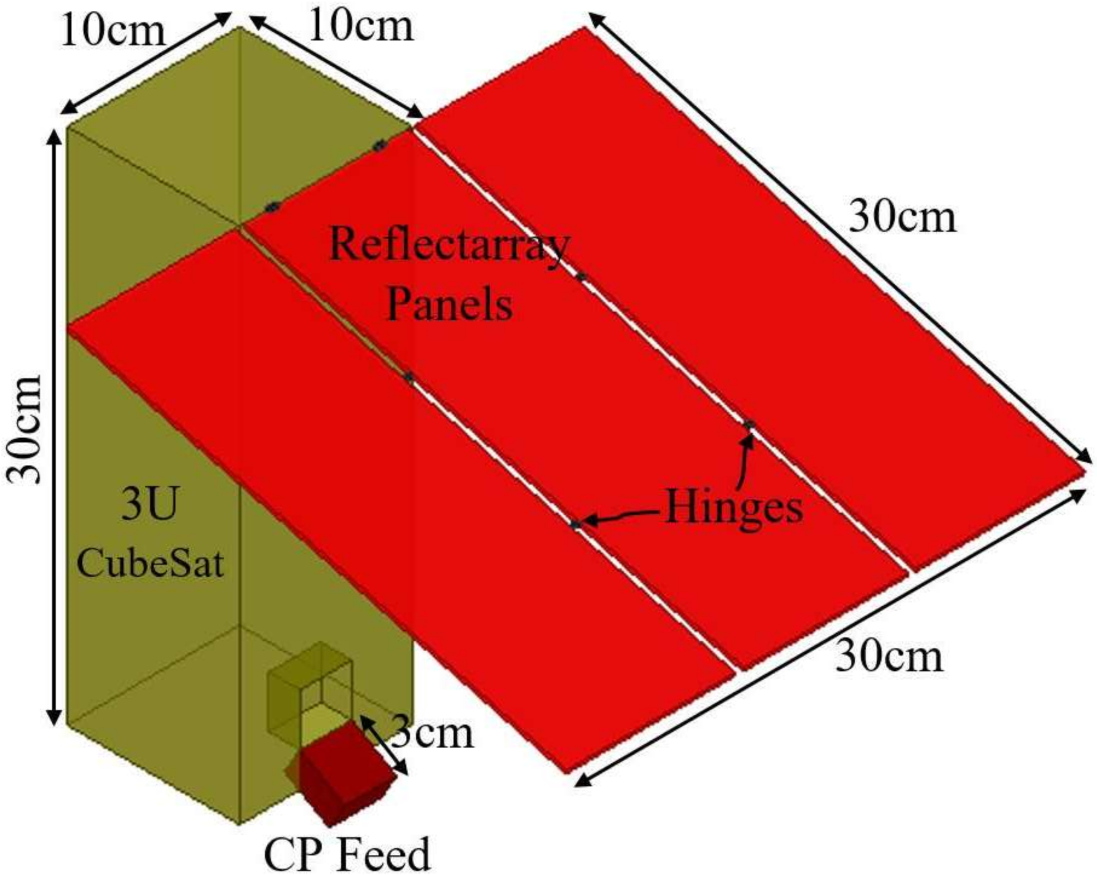




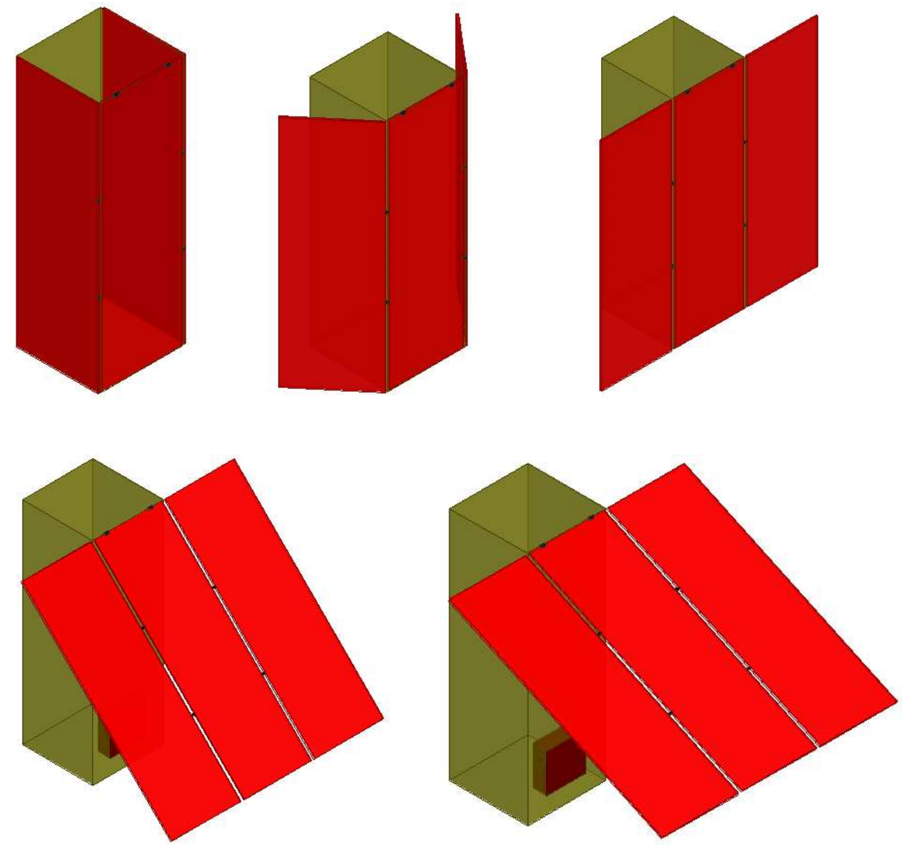
https://www.ausairpower.net/APA-Acquisition-GCI.html

S300 S-Band Russian Air Defense System

Small Spacecraft Technology



CubeSat 3U Layout

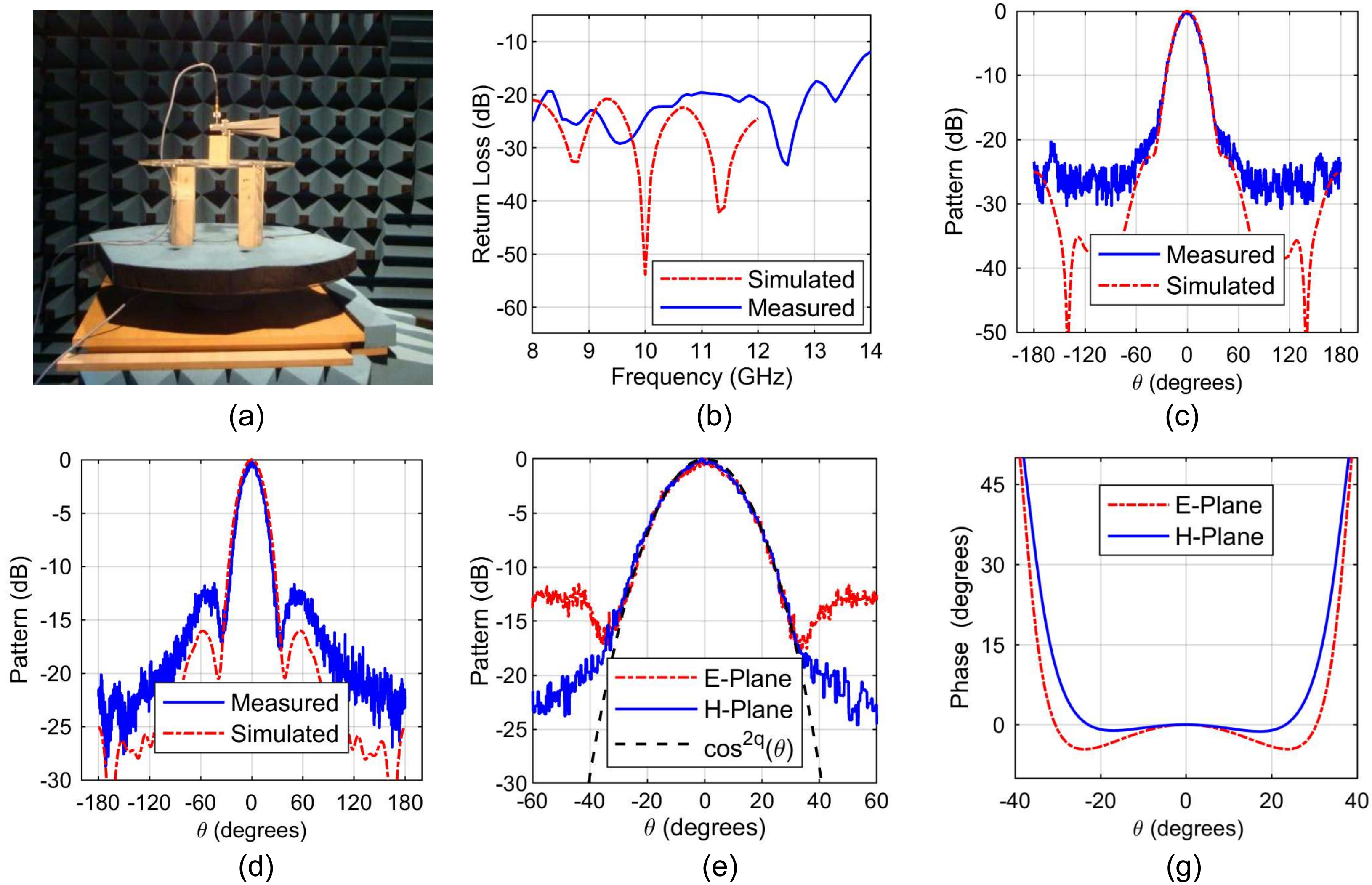


Procedure of Deployment

Mohammadi et. Al, KBEI 2019/10.1109/KBEI.2019.8735040

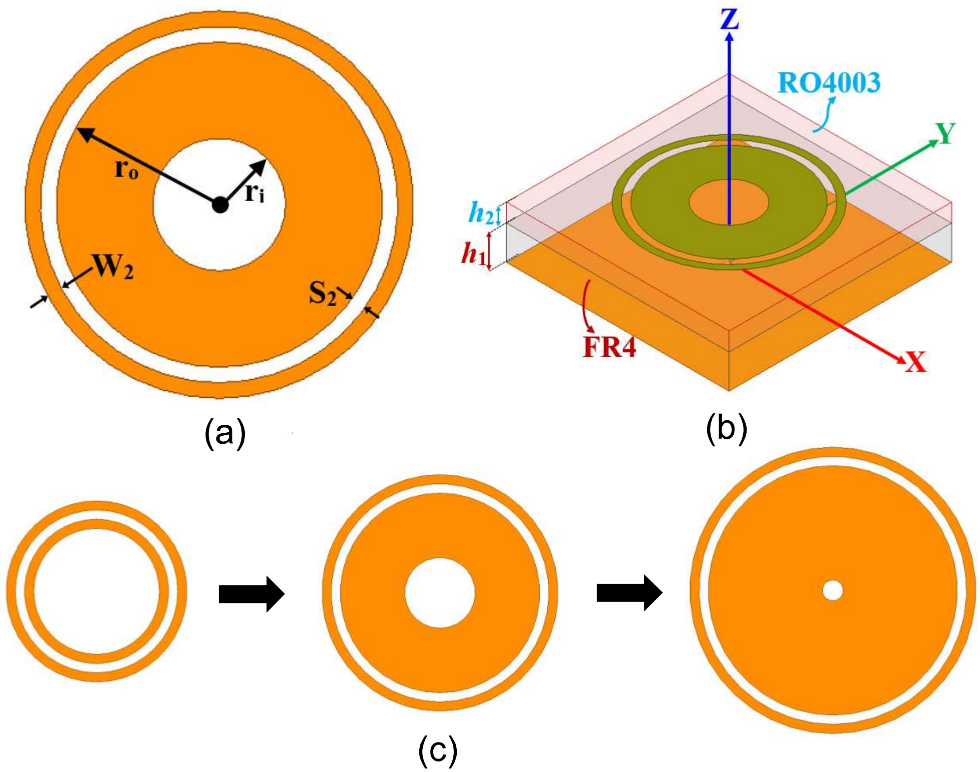
Satellite TV Dish Antenna

Afrika, Fez - Marokko, Marokko, Midden-Oosten, Noord-Afrika



X-band horn antenna: (a) under test, (b) return loss; radiation pattern at 10 GHz: (c) H-plane, (d) E-plane, (e) cosine q model of measured pattern with q = 12, and (g) simulation of phase variation along aperture.

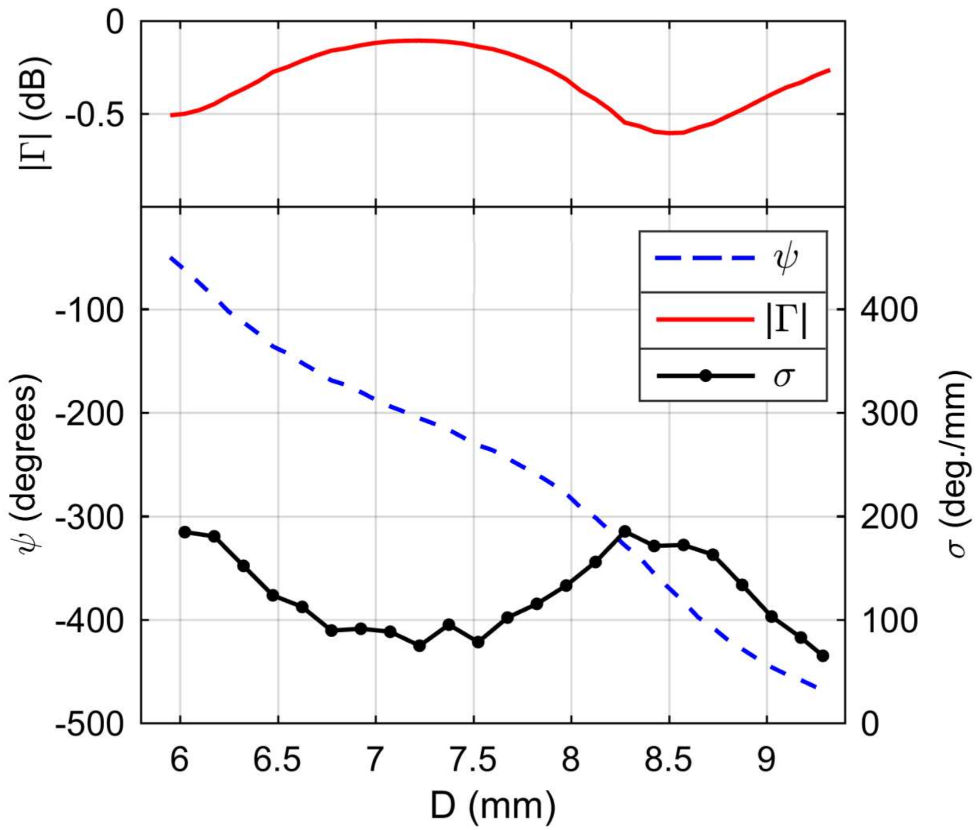
Elements Design



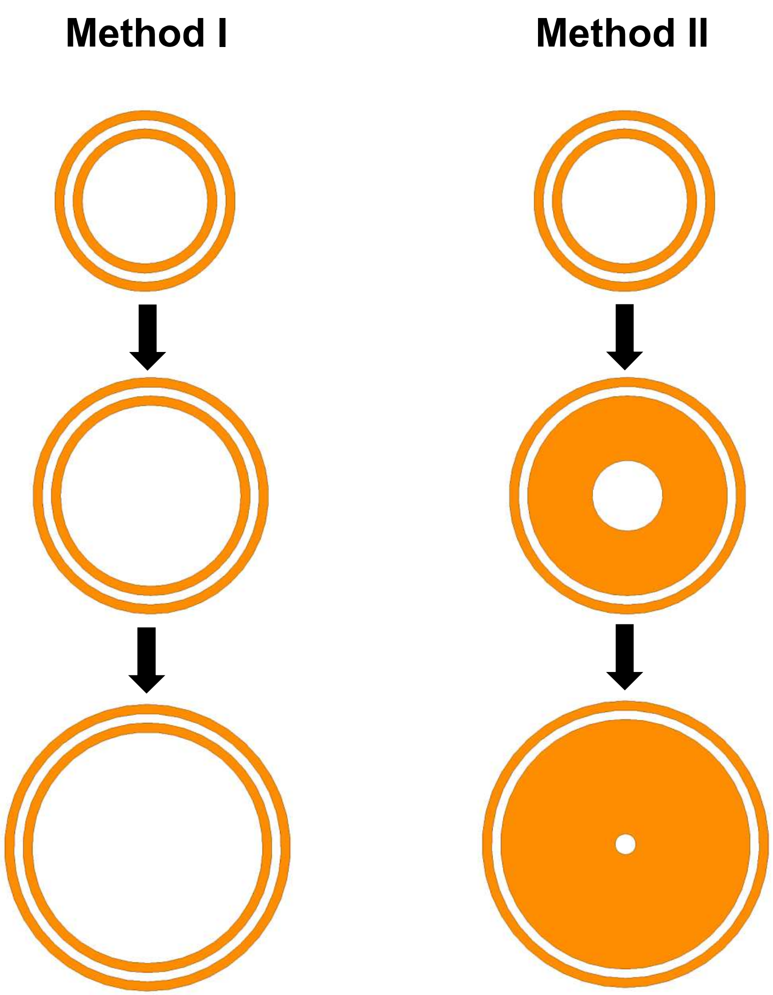
The designed unit element with sub-wavelength spacing: (a) top-, (b) side-view, and (c) process of design.

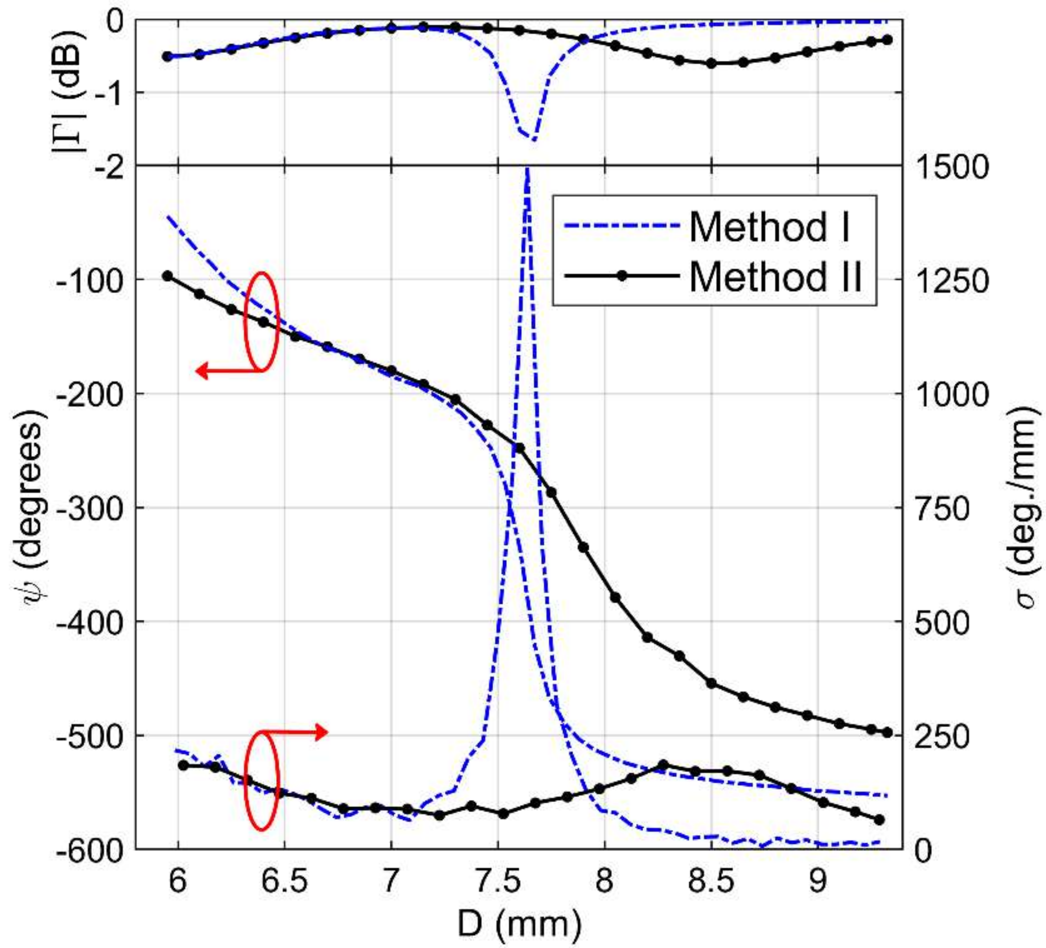
S_2=0.3mm, W_2=0.3mm, r_o=0.125D, r_i=a-br_o, b=1,

a=4.3mm, D = 2 × (r_o + S_2 + W_2), h_1=1.6mm, h_2=0.8mm.

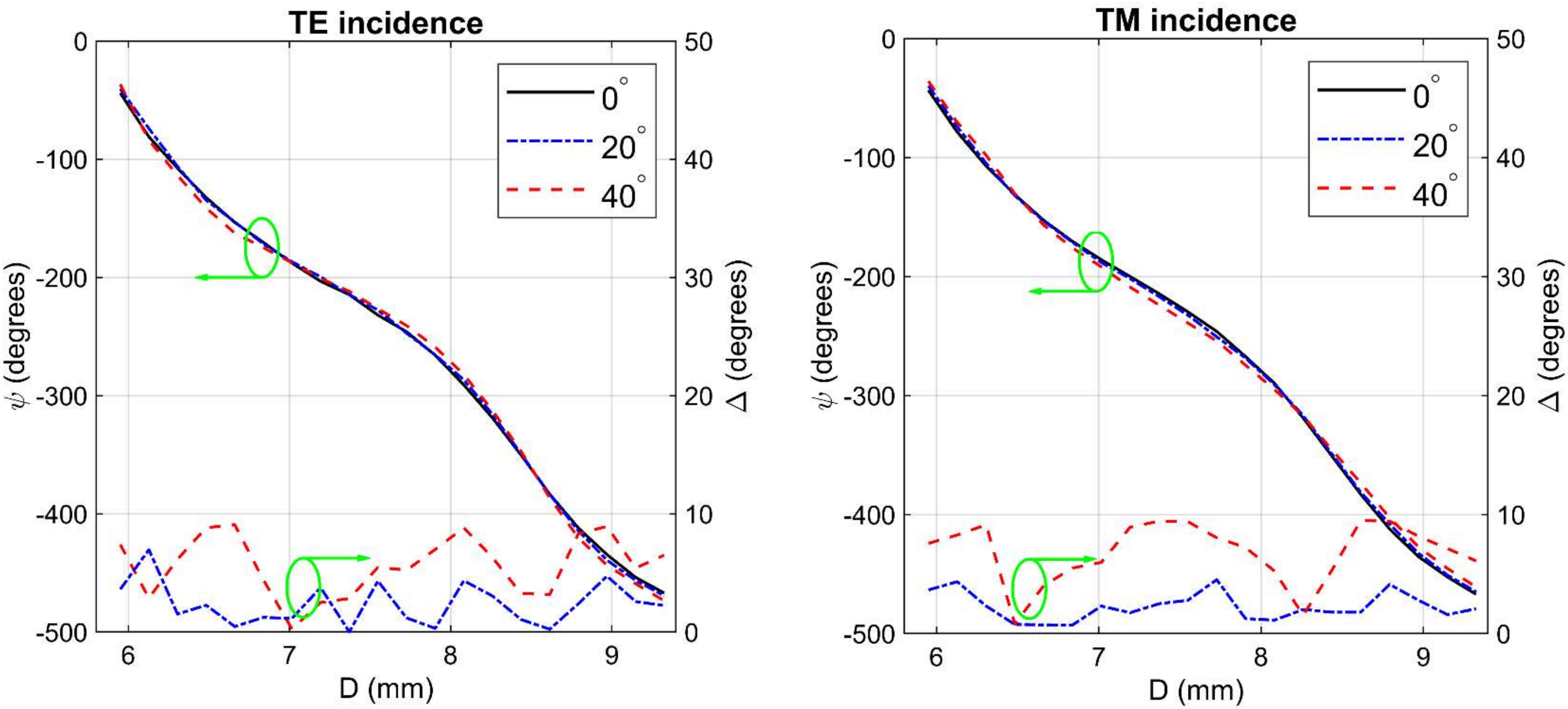


The reflection properties of the designed unit element at 10 GHz.





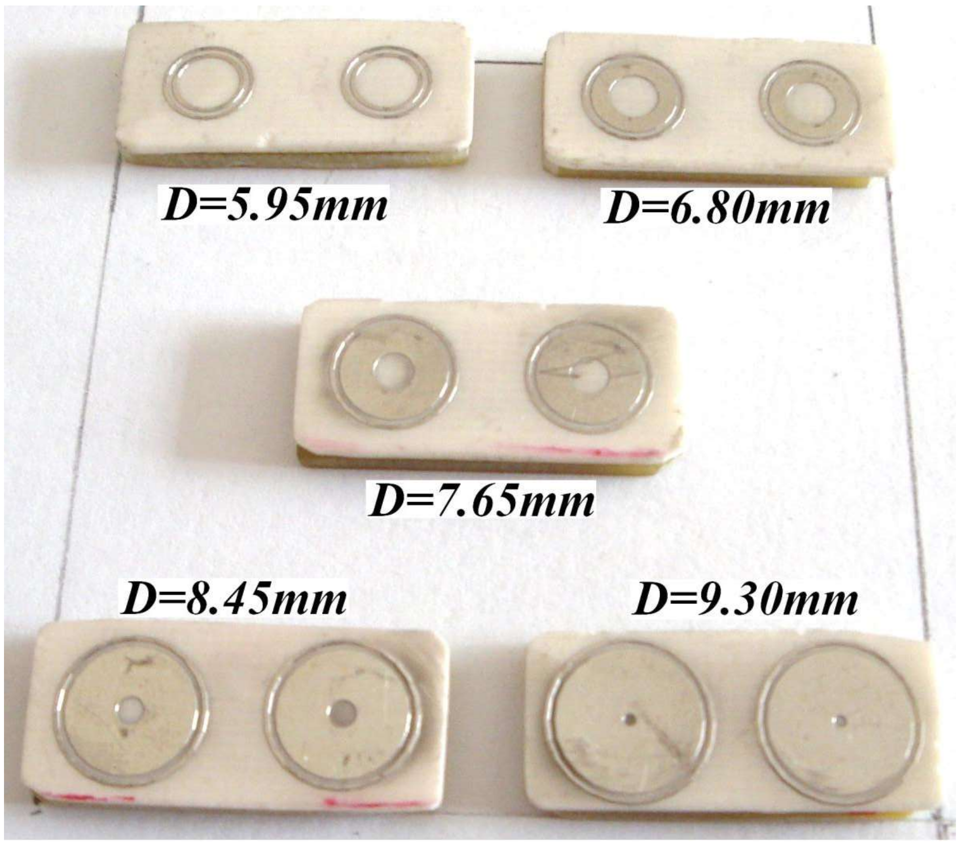
Different designed procedures and comparison of reflection characteristics at 10 GHz.



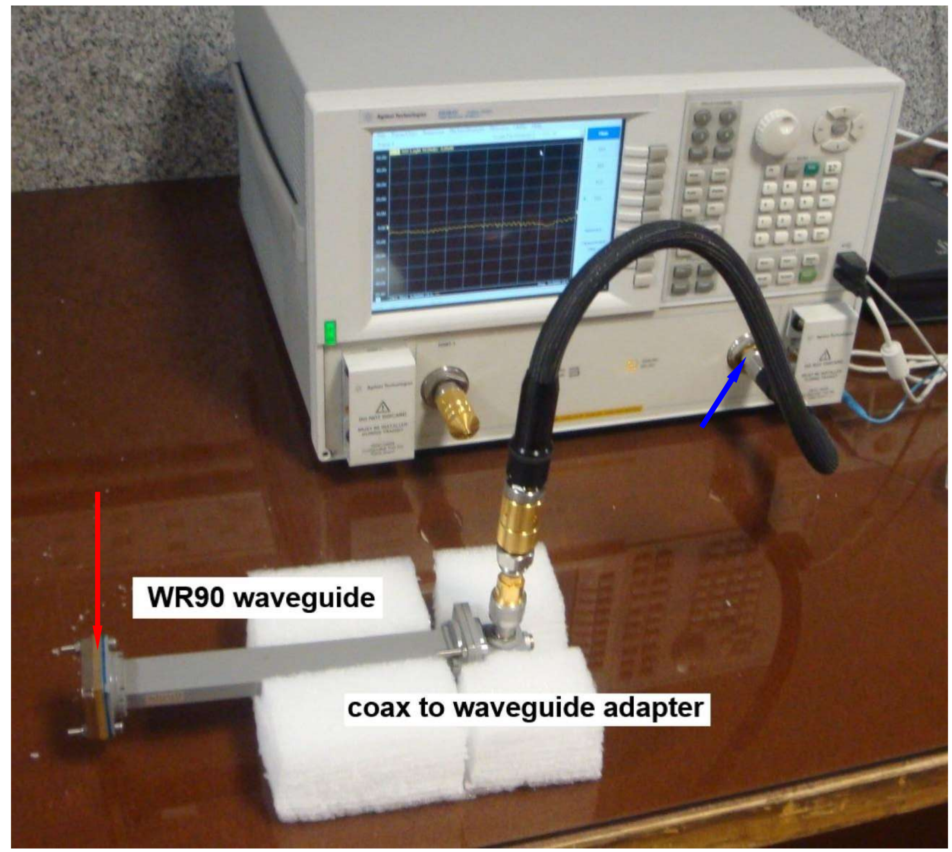
Reflection phase (ψ) and phase difference ($\Delta = \psi(\theta_{inc}) - \psi(0°)$) of the unit element designed with Method II at 10 GHz.

$$E_i = E_{i,TE} + E_{i,TM},\ E_{i,TE} = \hat{y}E_y,\ E_{i,TM} = \hat{x}E_x + \hat{z}E_z \Rightarrow \Gamma_\perp = \Gamma^{TE}(\theta_i),\ \Gamma_\parallel = \Gamma^{TM}(\theta_i)$$

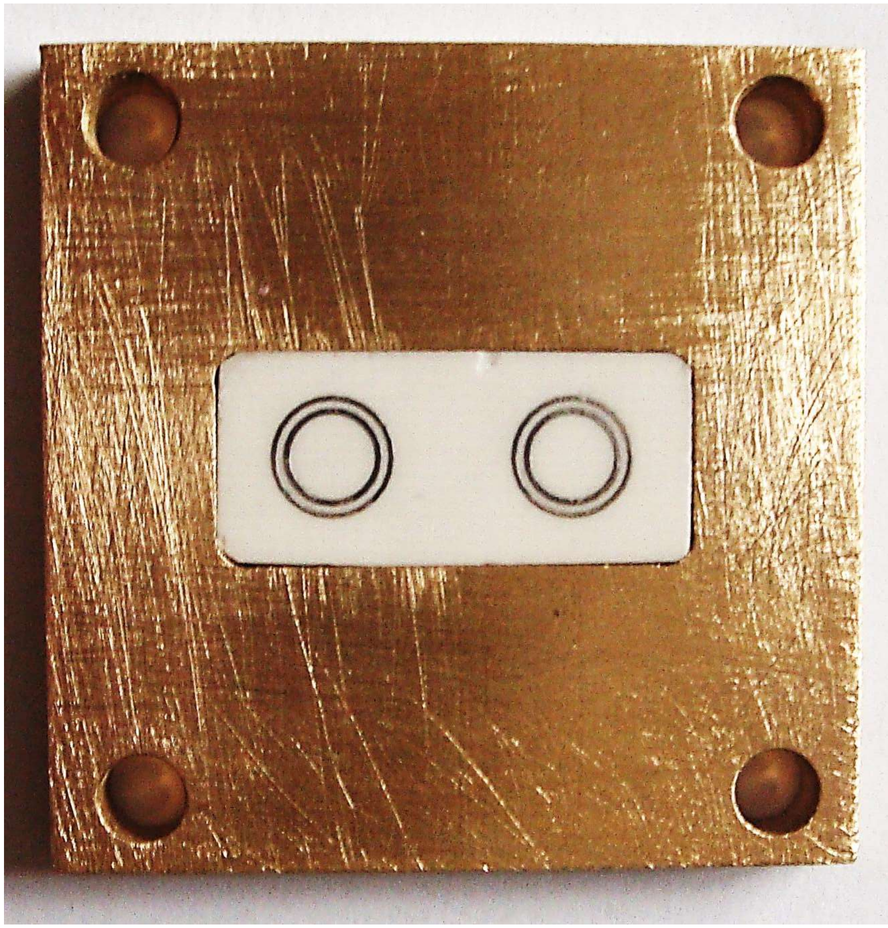
Elements Measurement Procedure



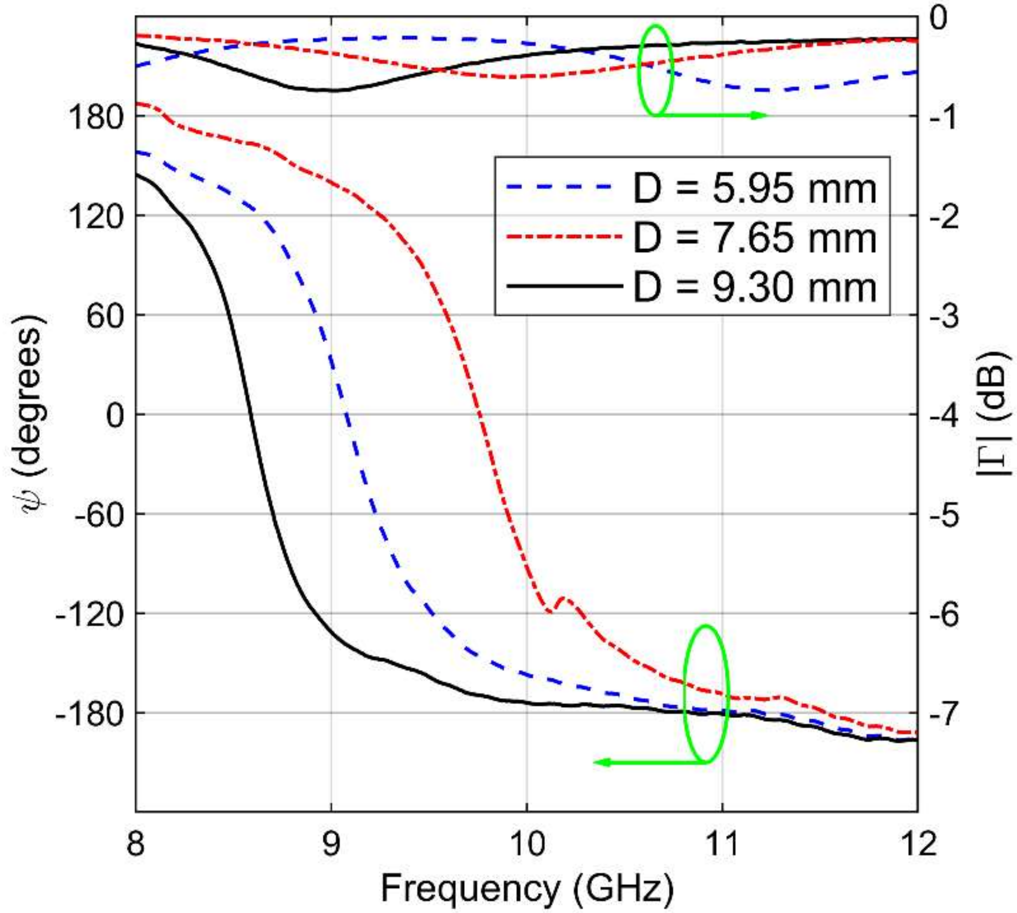
Prototypes of the fabricated unit elements



Waveguide measurement setup

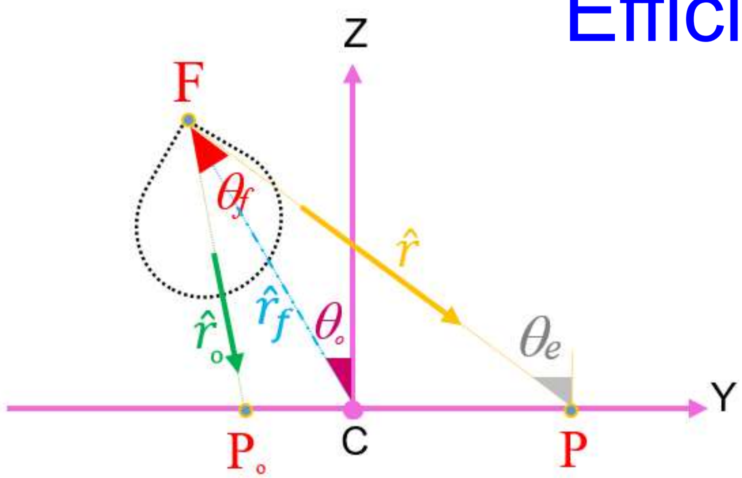


Sample holder

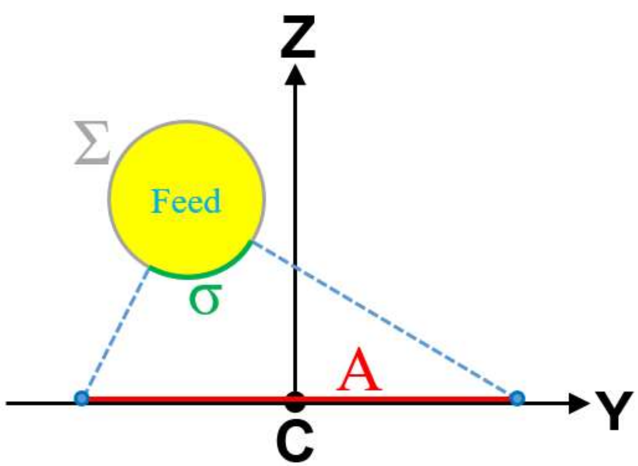


TE_{10} Mode ($\theta_{inc} \neq 0$)

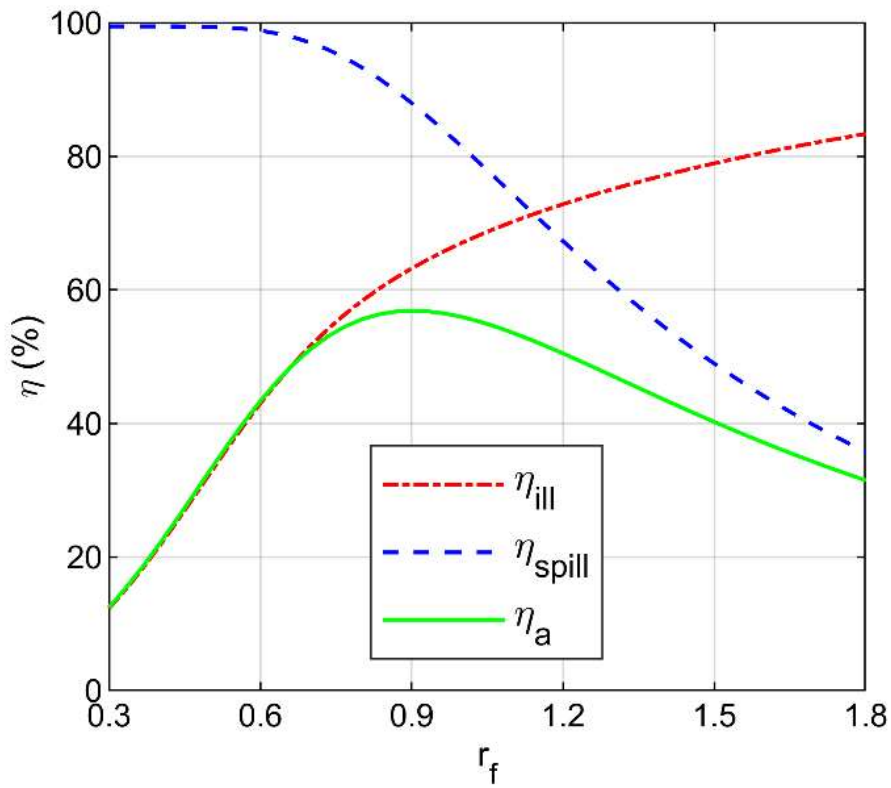
Efficiency Analysis



Configuration parameters of a typical reflectarray.



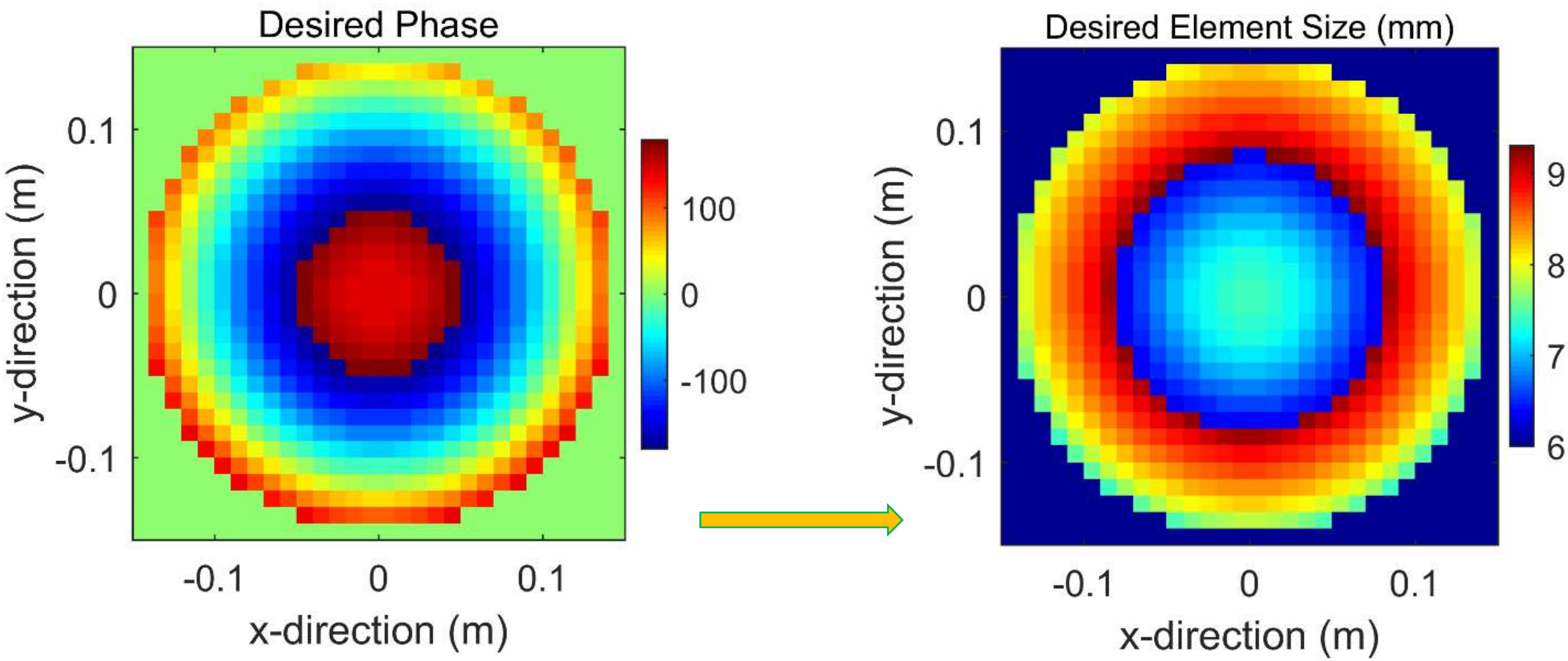
Spherical geometry of a typical reflectarray antenna.



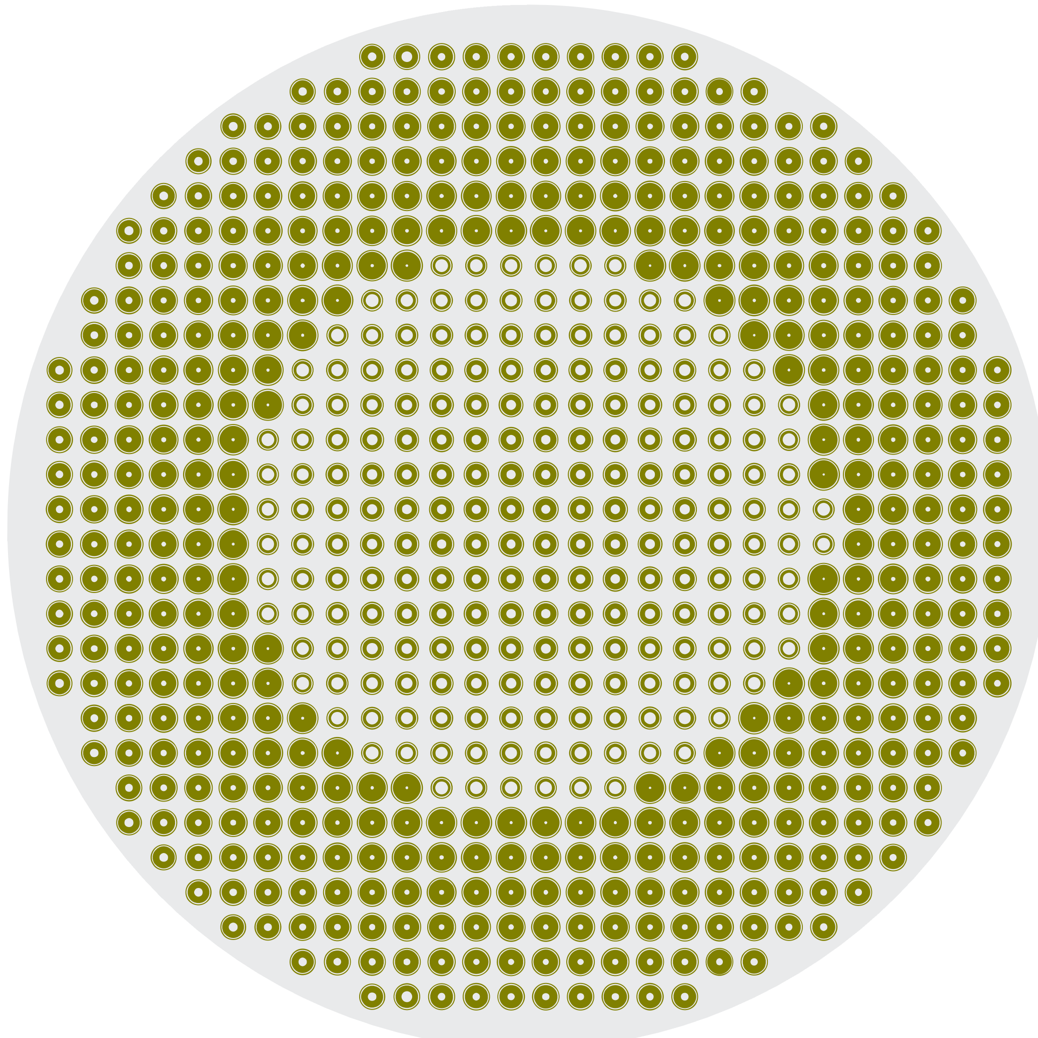
η_{ill}, η_{spill}, and η_a = 57% ($\eta_a = \eta_{ill} \times \eta_{spill}$) for a circular aperture with diameter of 30cm, θ_o=15, and q_f=12.

Implementation

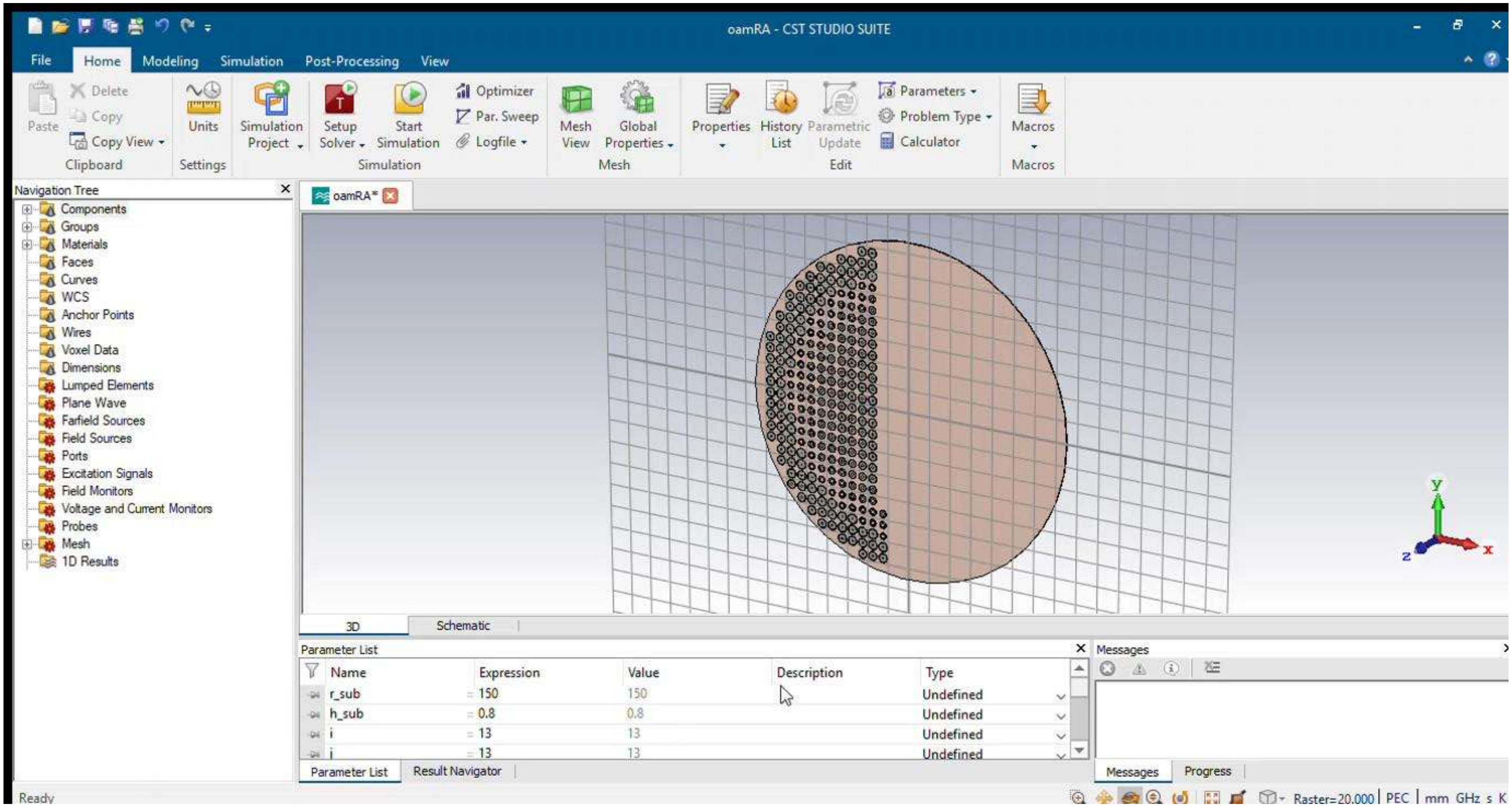
15° offset-feed and 15° offset-beam

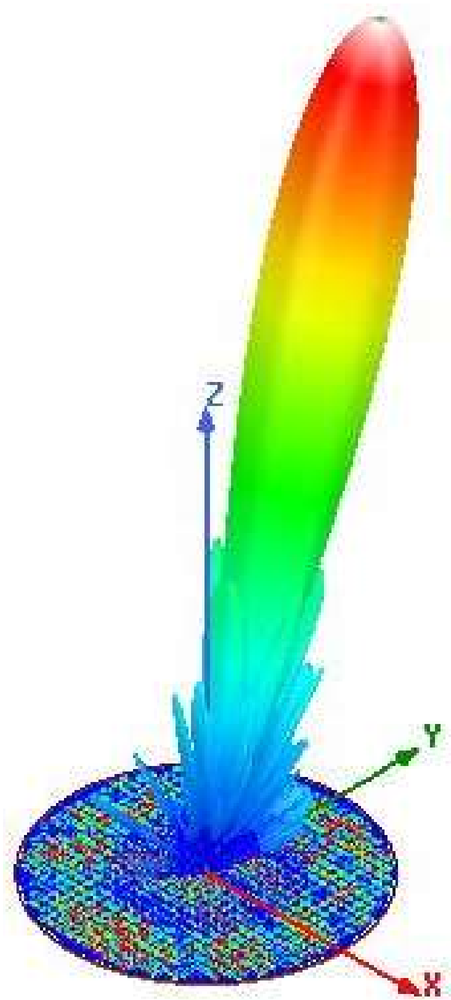


Antenna Layout

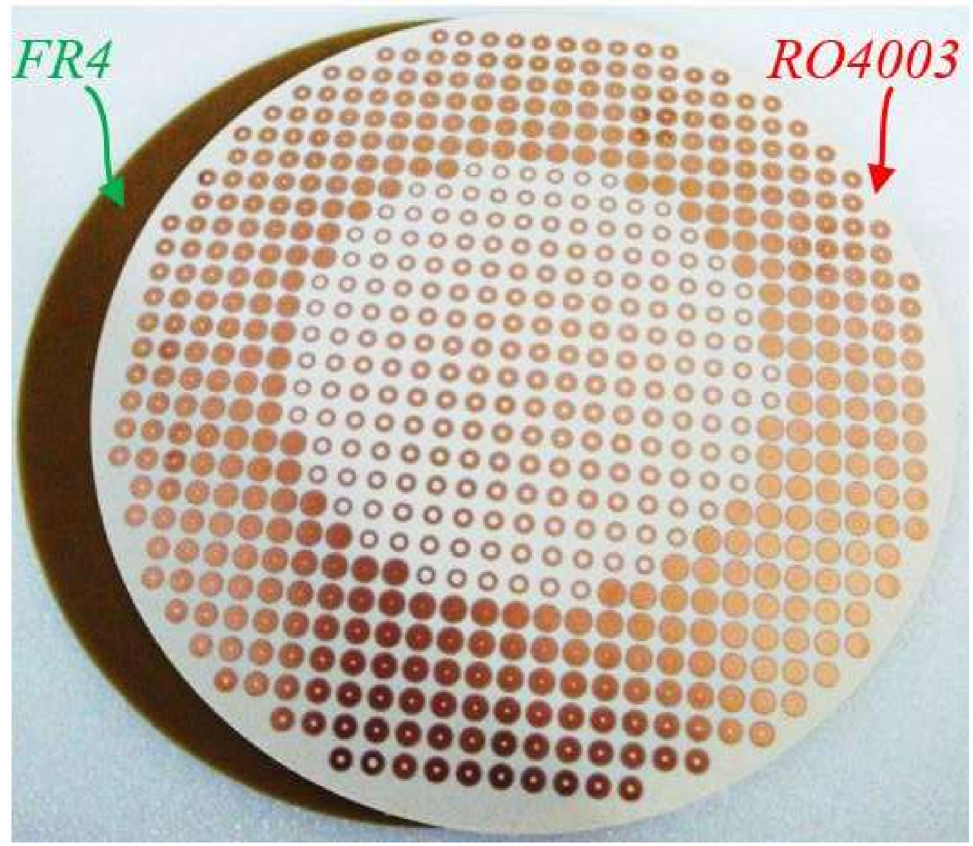


Online Mask Generation

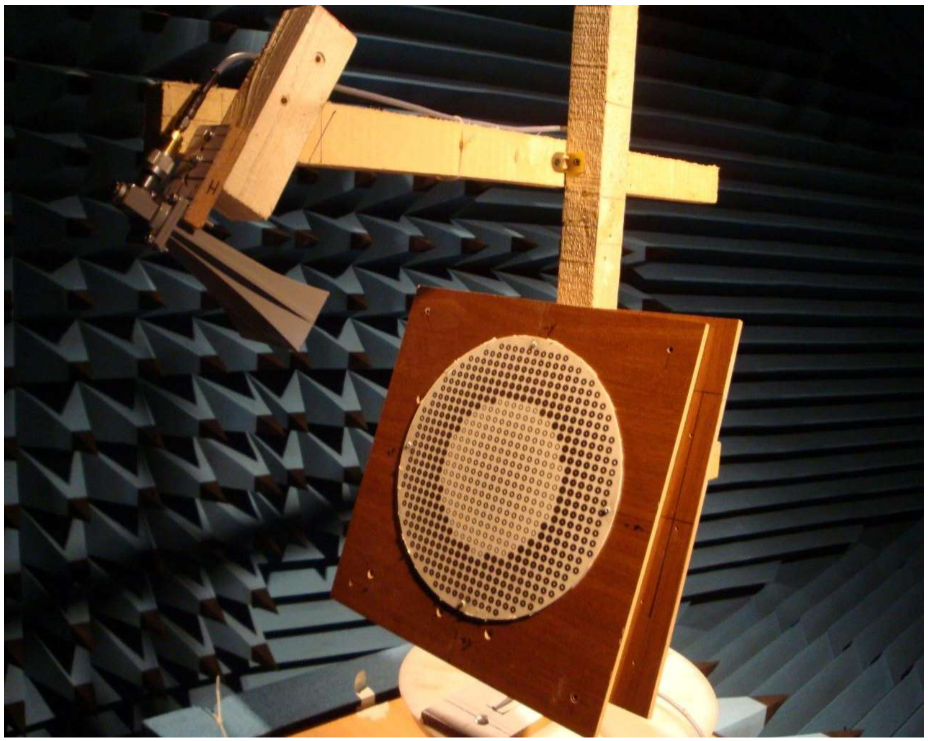




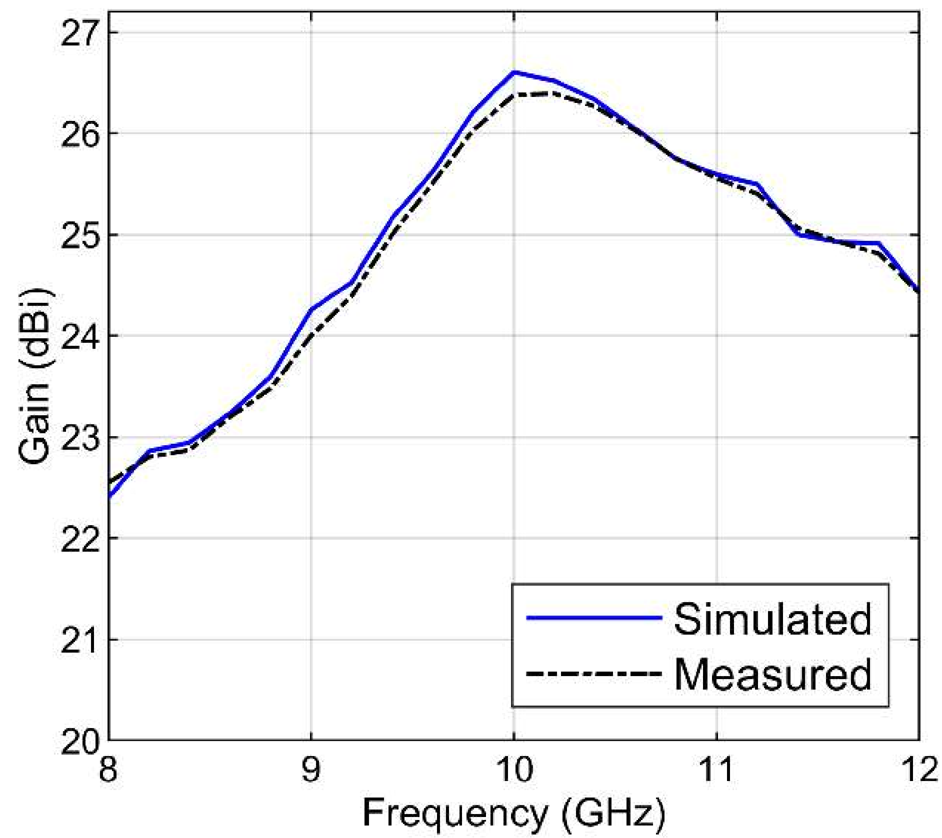
Simulated 3D radiation pattern at 10 GHz.
Hybrid Finite Element Boundary Integral (FEBI) method



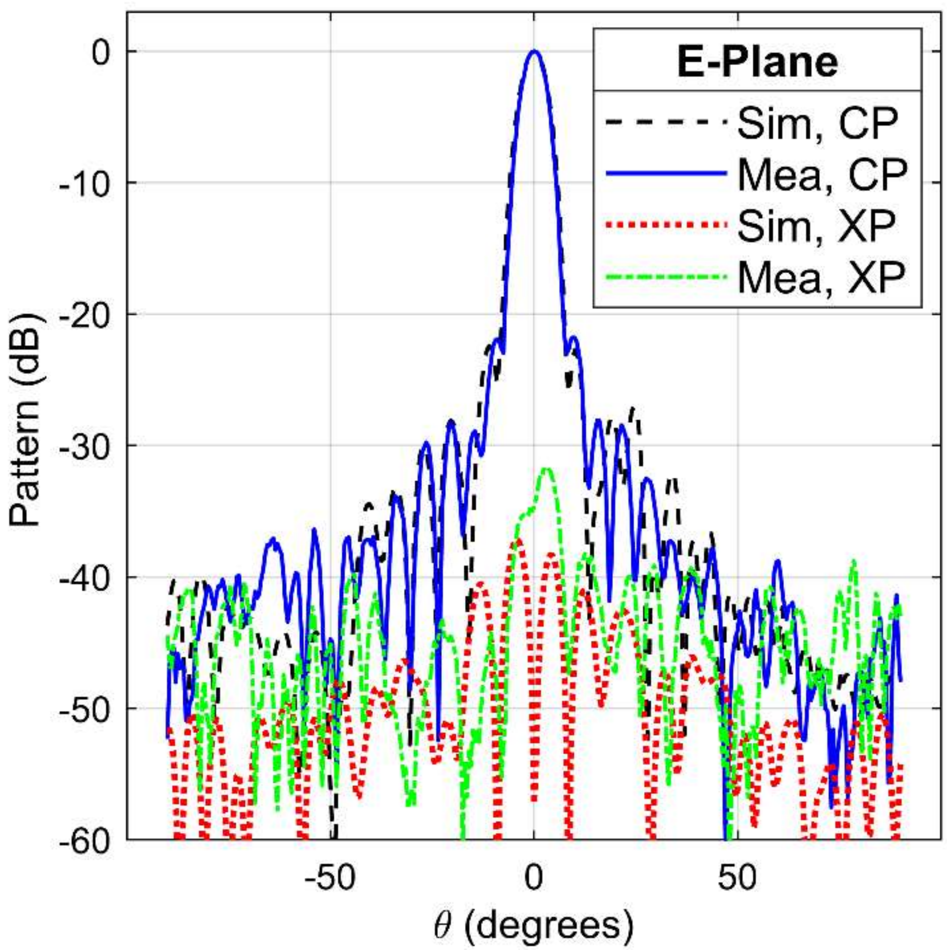
Photograph of the fabricated prototype antenna

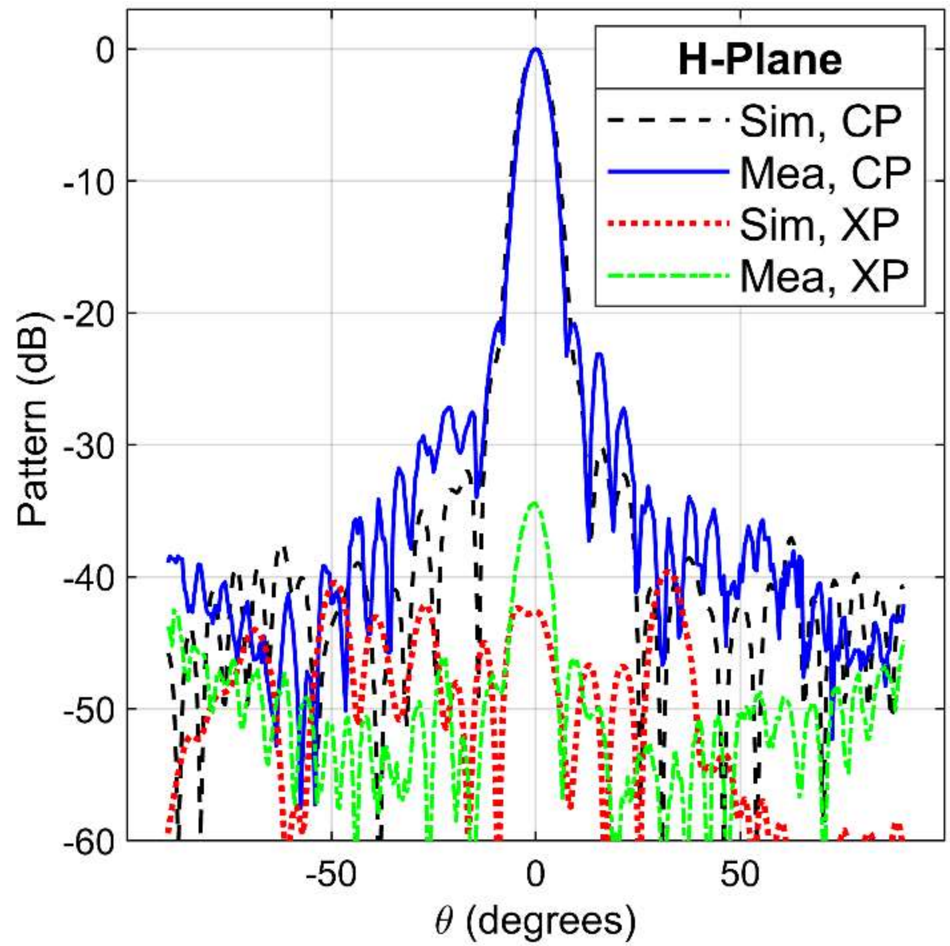


Photograph of the reflectarray measurement setup

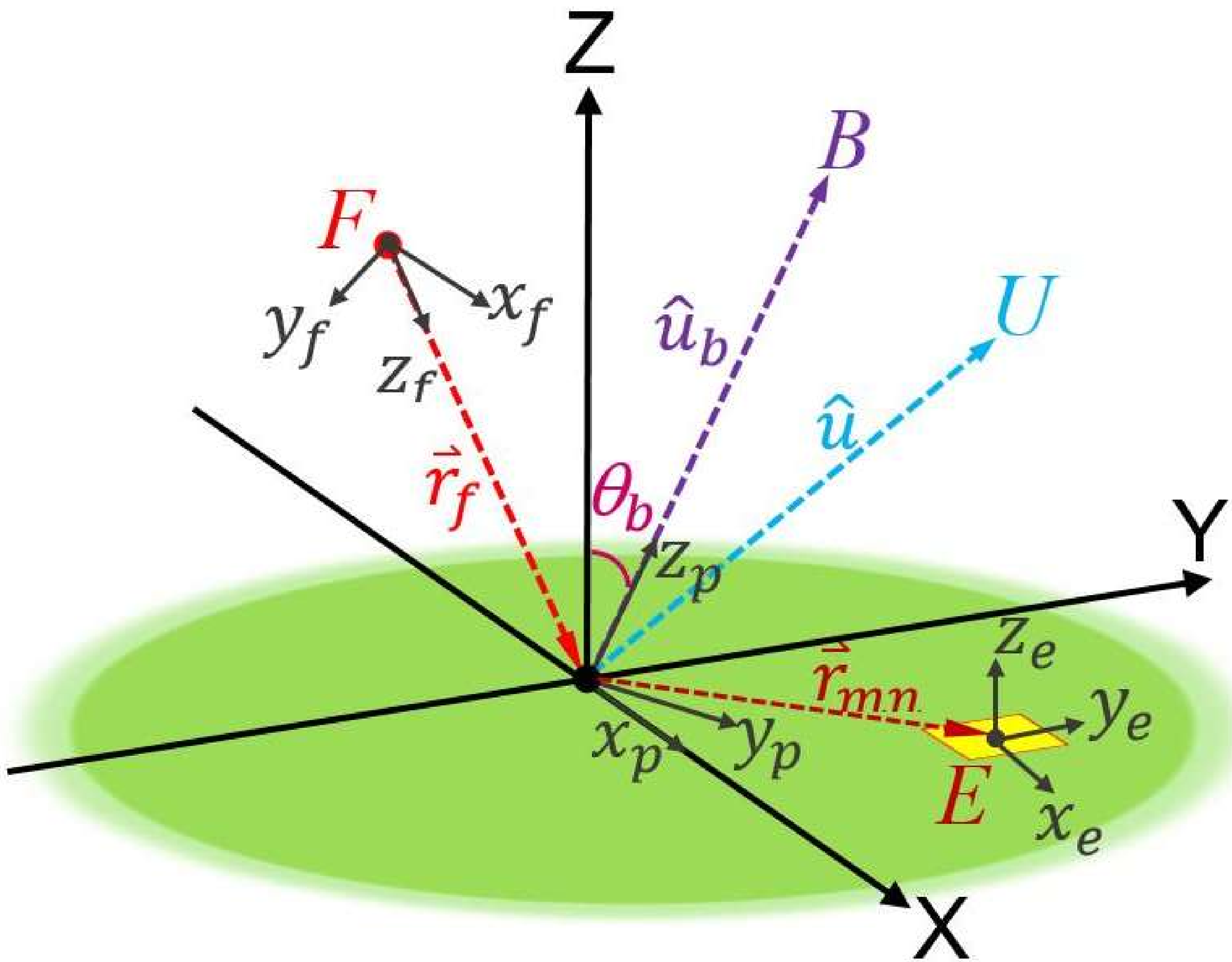


Simulated and measured gain characteristics

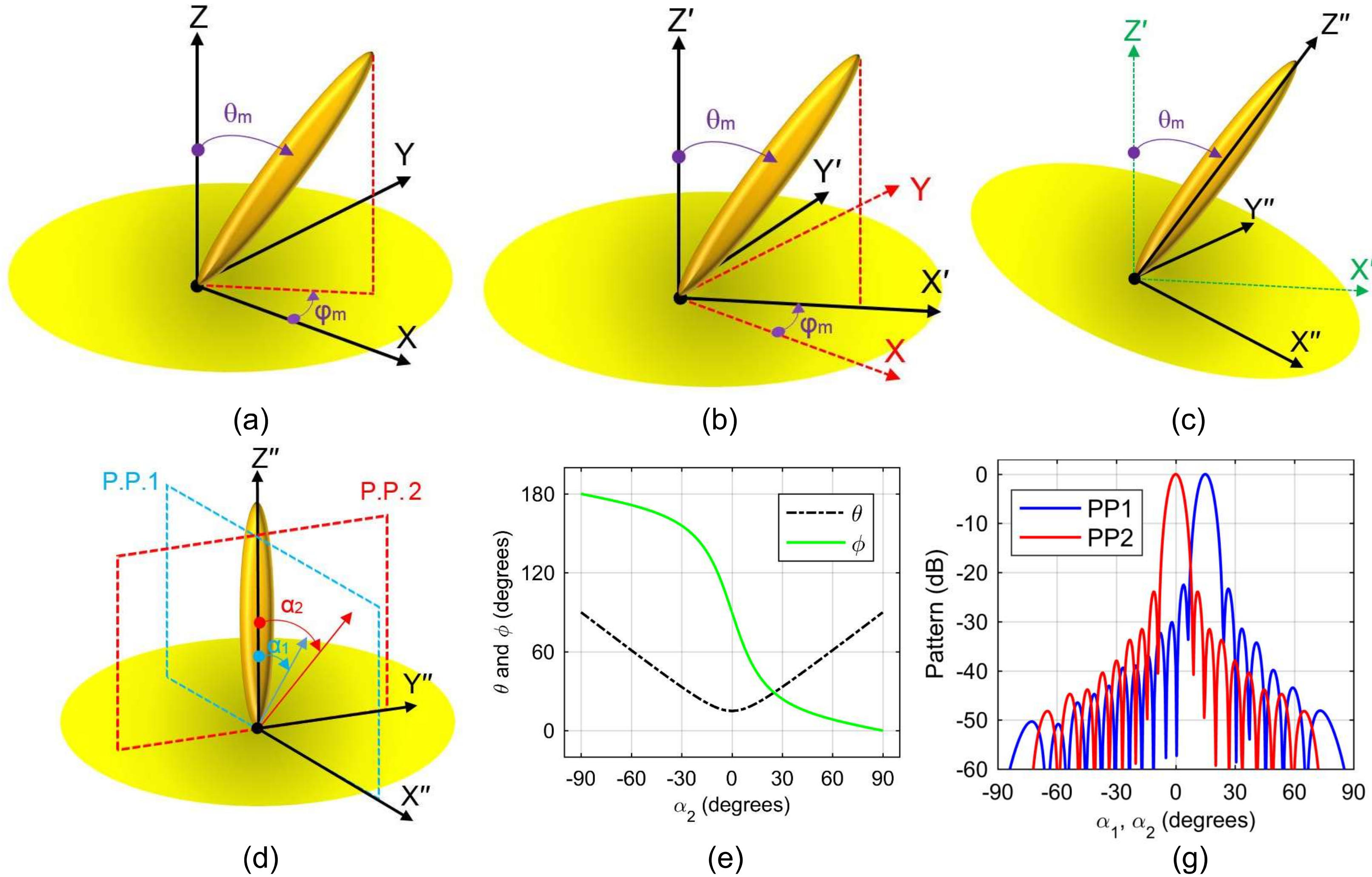

E-Plane
Sim, CP
Mea, CP
Sim, XP
Mea, XP
Pattern (dB)
0
-10
-20
-30
-40
-50
-60
-50
0
50
θ (degrees)


H-Plane
Sim, CP
Mea, CP
Sim, XP
Mea, XP
Pattern (dB)
0
-10
-20
-30
-40
-50
-60
-50
0
50
θ (degrees)

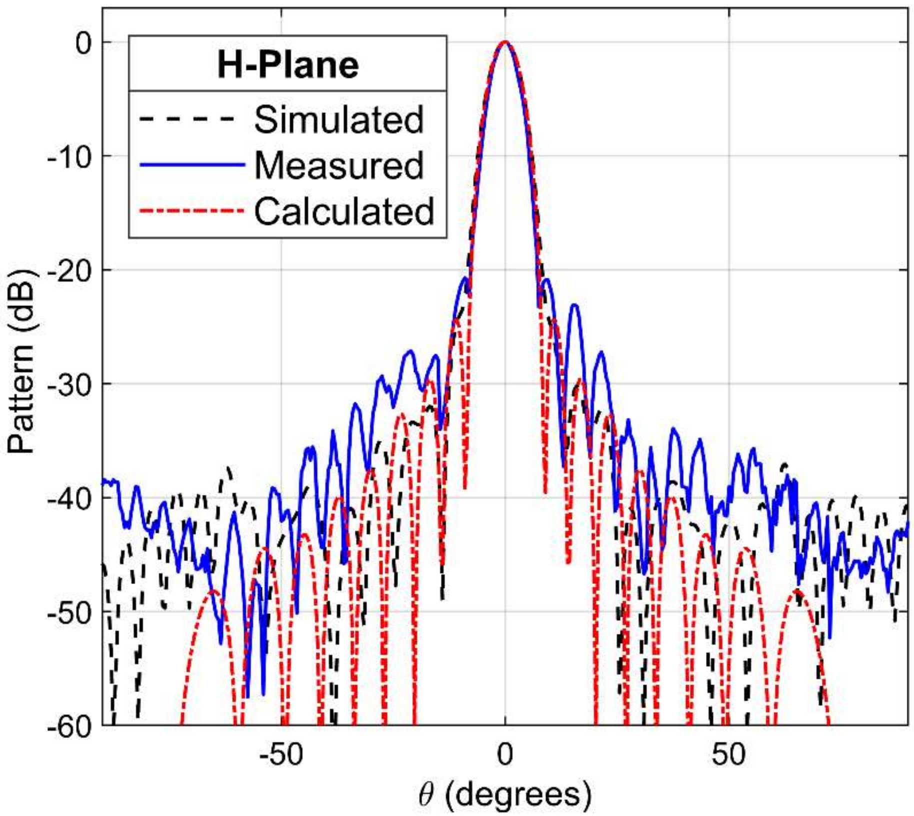
Array-Theory Method

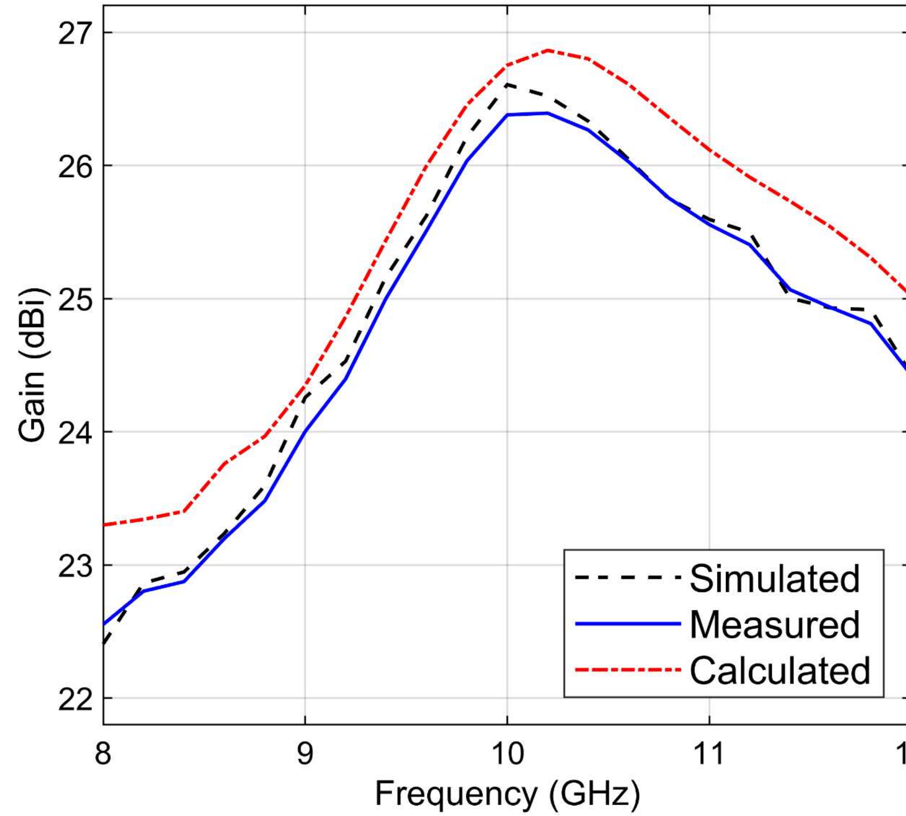


Coordinate Systems

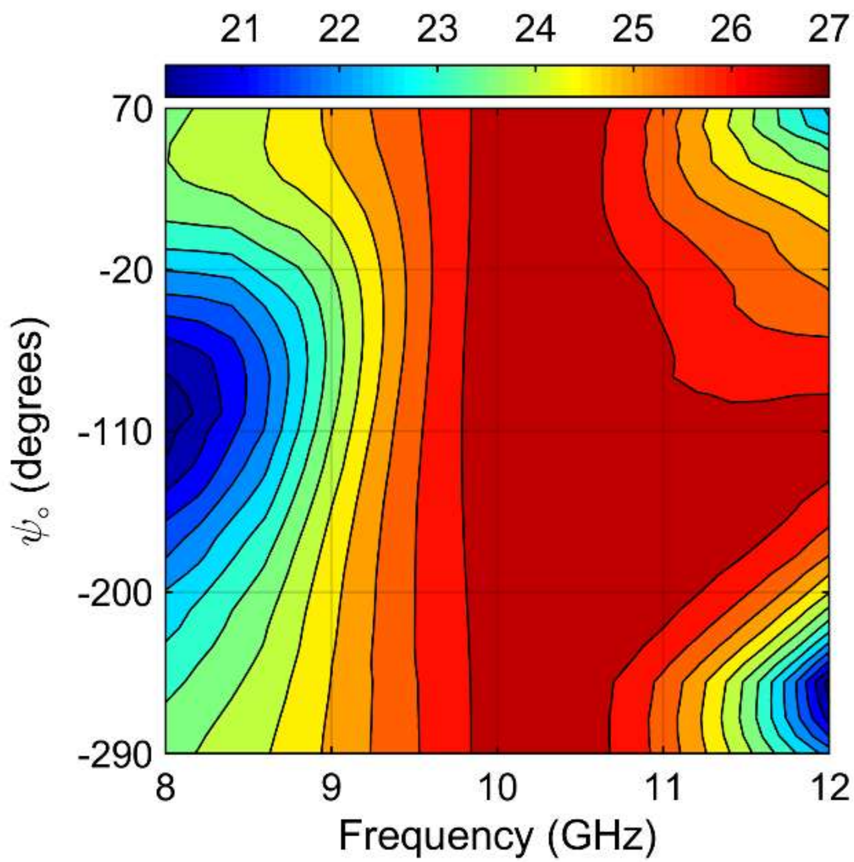


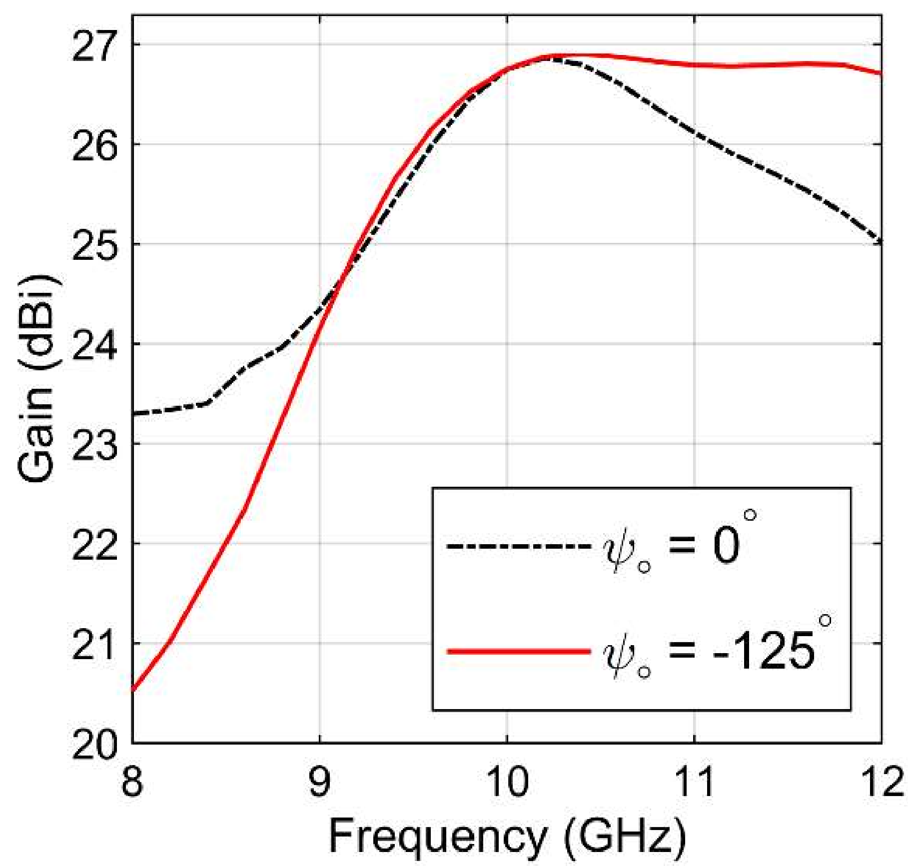
Principle Planes: (a) Coordinate system for RA, (b) rotation of ϕ_m around *z*-axis, (c) rotation of θ_m around *y*-axis, (d) principal planes of RA, (e) the relation (θ, ϕ) with α_2 for RA with ϕ_b=90° and θ_b=15°, and (g) the radiation patterns in PP1 and PP2 at 10 GHz.





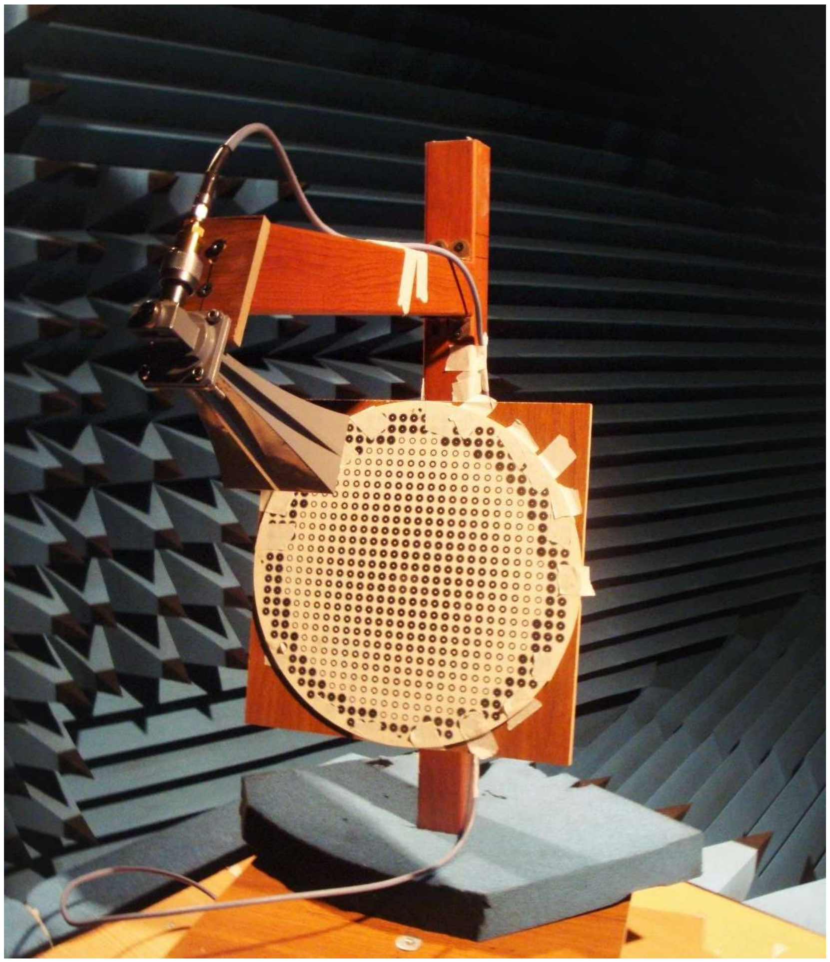
The gain and efficiency of the fabricated antenna at 10GHz were **26.4 dBi** and **44.27%,** respectively, and 1dB gain bandwidth was found to be equal to **16.3%.**



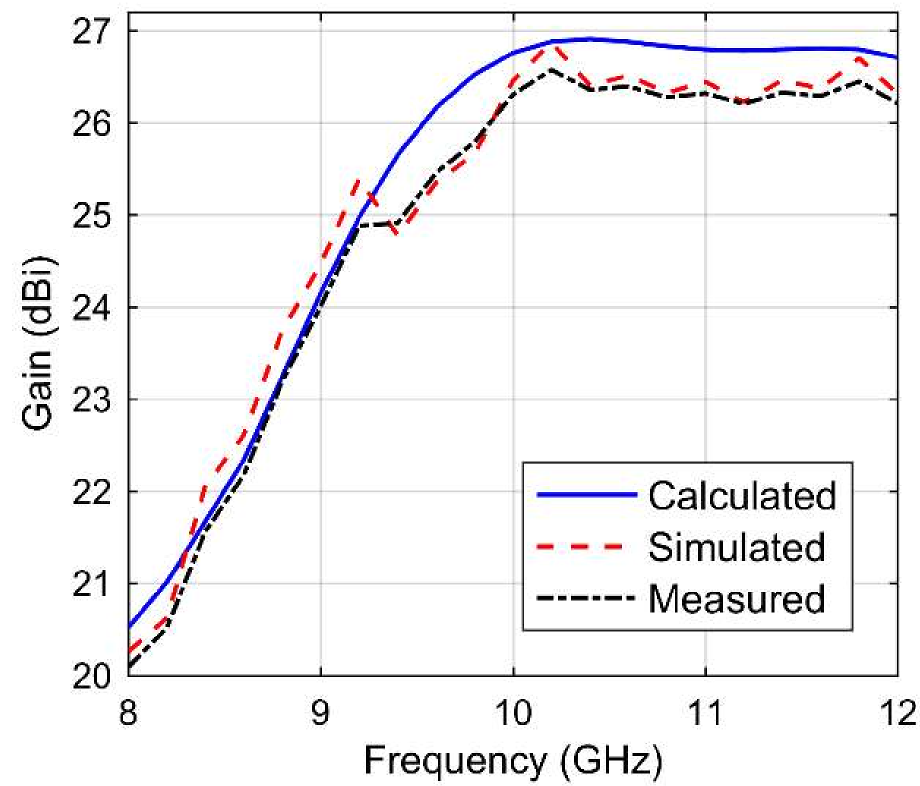


Calculated gain for various phase constant $(\psi_\circ)$ values at the RA aperture:

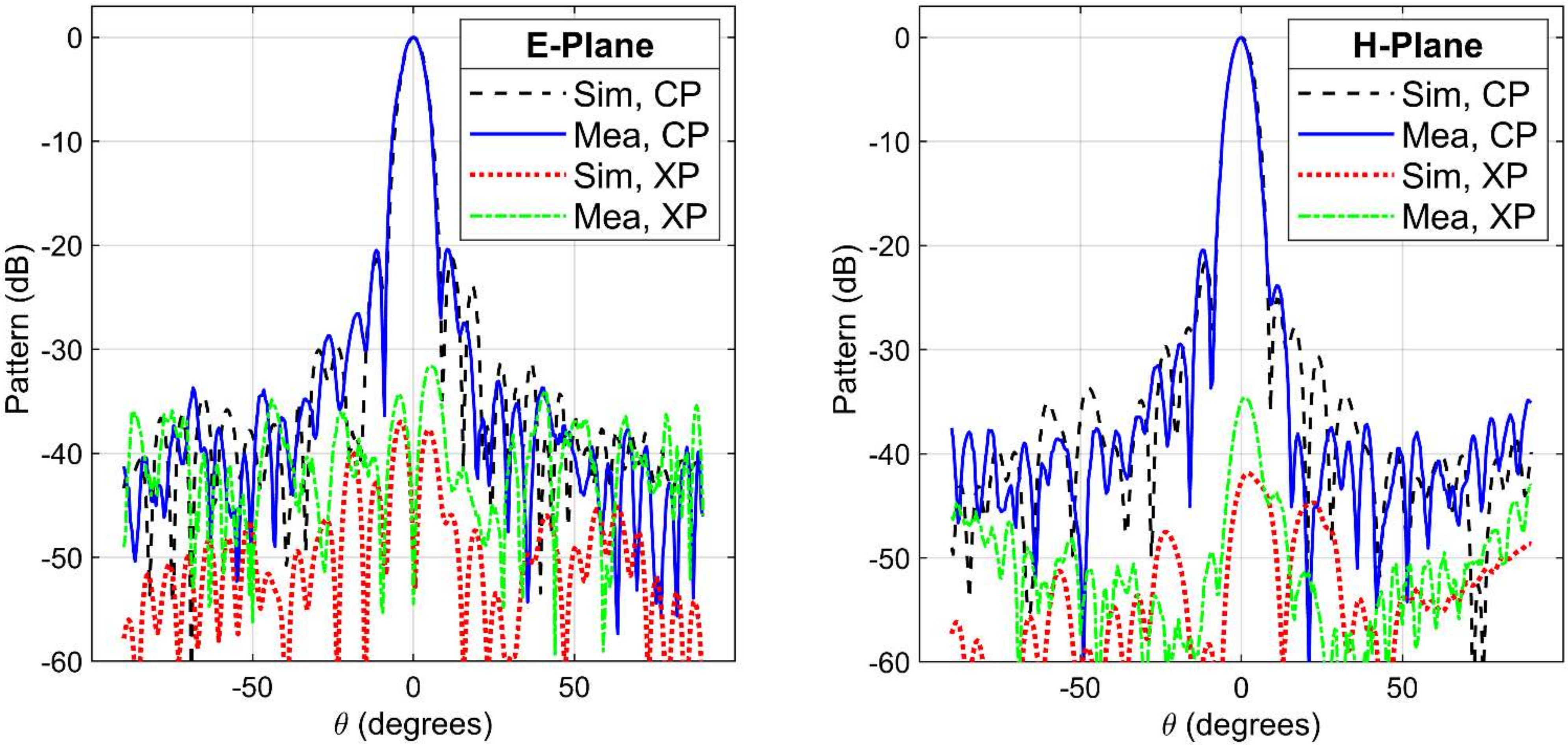
(a) full cycle (-290°~70°), (b) $\psi_\circ = 0^\circ$ and $\psi_\circ = -125^\circ$.



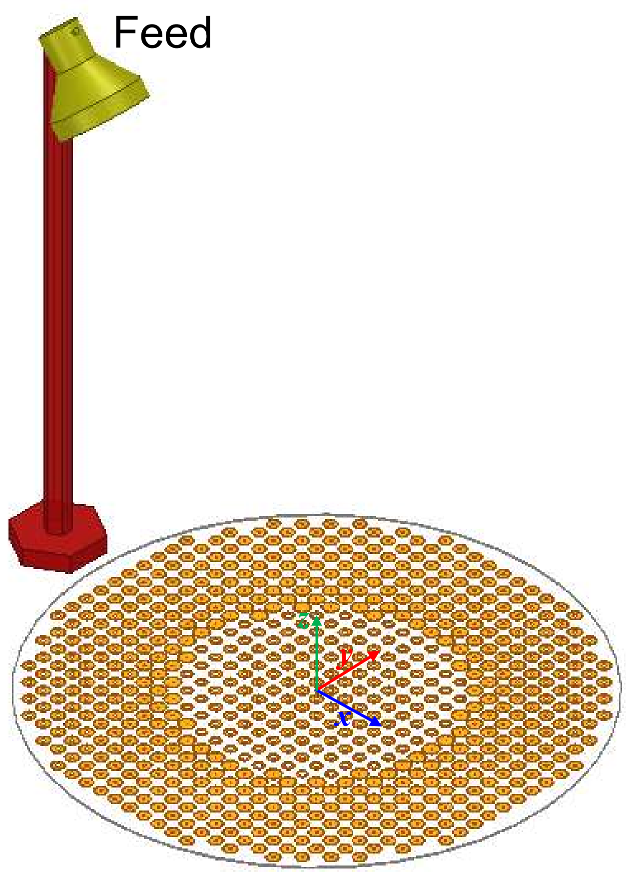
Fabricated prototype RA with phase constant ($\psi_{\circ}$) of -125°



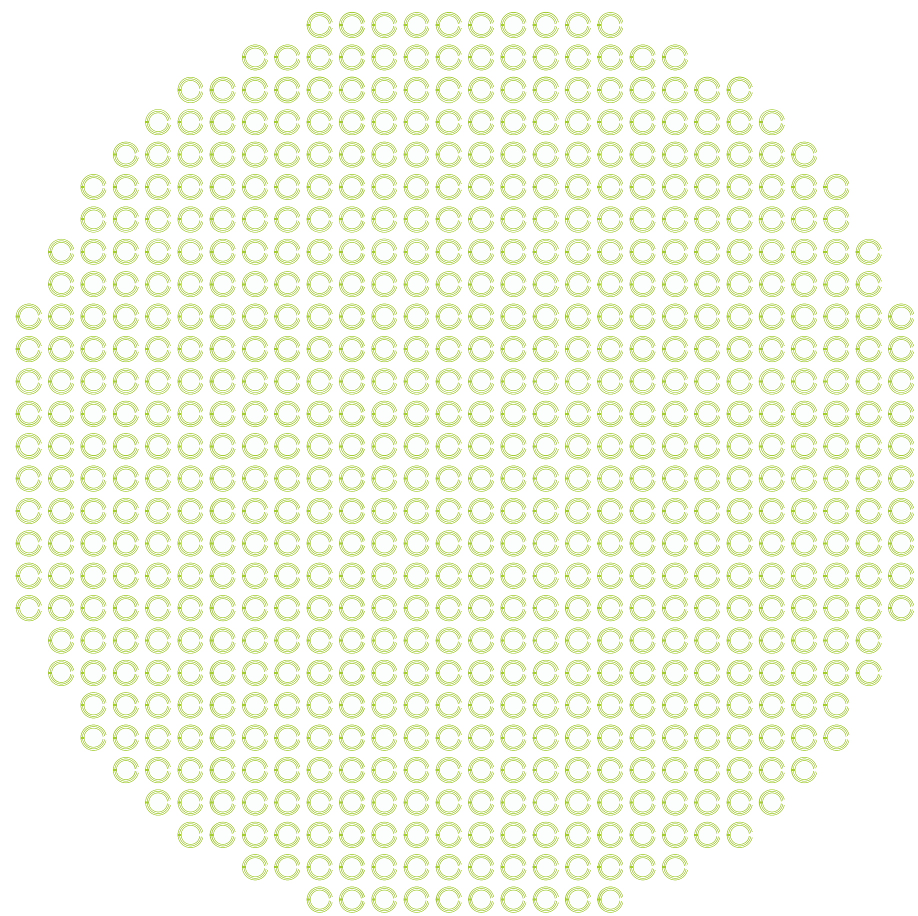
The gain and efficiency of the fabricated antenna at 10GHz were **26.87 dBi** and **44.27%,** respectively, and 1dB bandwidth was found to be equal to **23.3%.** The 1dB gain bandwidth of RA antenna with $\psi_{\circ}$= -125° shows an improvement of **43%** to $\psi_{\circ}$= 0°.


E-Plane
Sim, CP
Mea, CP
Sim, XP
Mea, XP
Pattern (dB)
θ (degrees)
H-Plane
Sim, CP
Mea, CP
Sim, XP
Mea, XP
Pattern (dB)
θ (degrees)

FSS-Backed Reflectarray Antenna

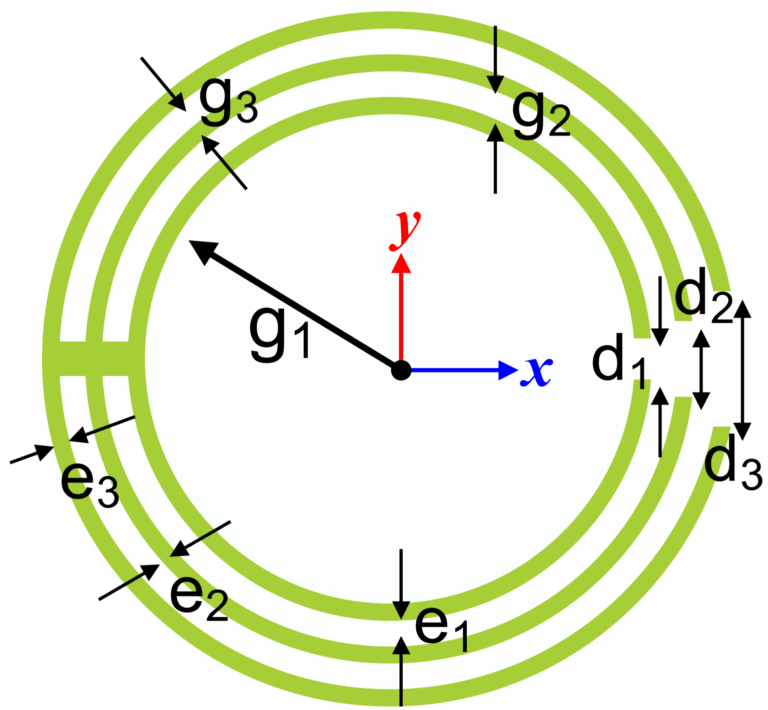


Antenna Aperture



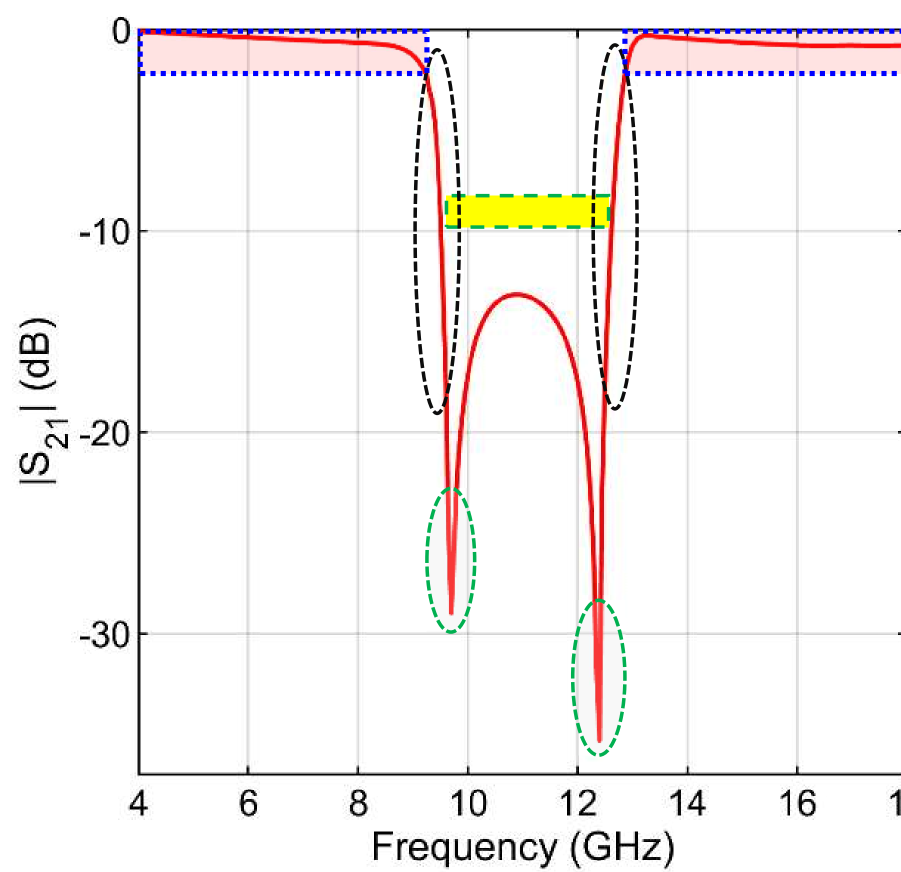
Frequency Selective Surface (FSS)-Backed Layer

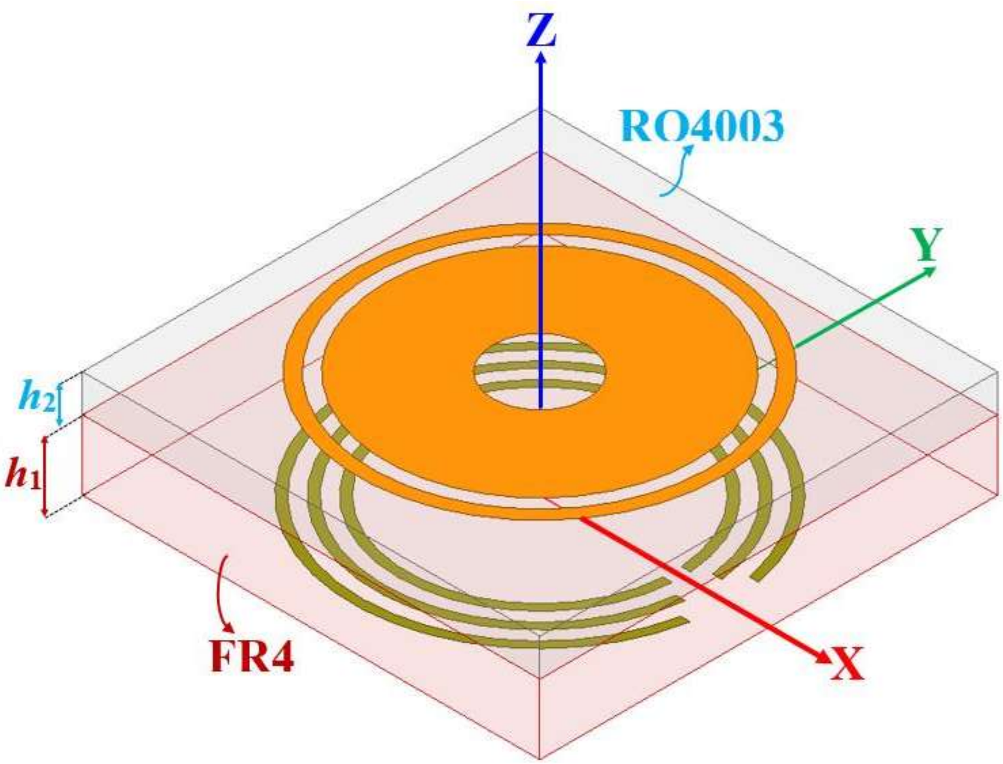
Radar Cross Section (RCS) Reduction Performance



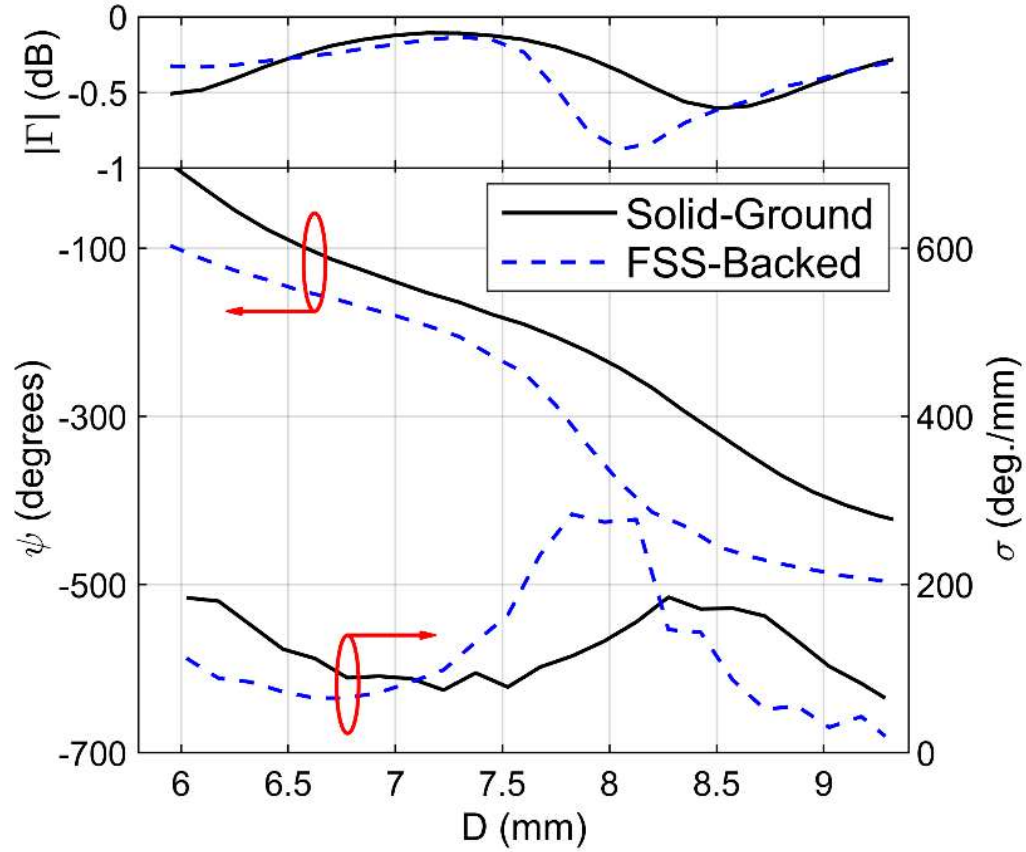
g_1= 2.9 mm, g_2=g_3=0.2m, e_1=e_2=e_3=0.2 mm, e_4=0.3 mm,

d_1=0.4 mm, d_2=0.8 mm, d_3=1.5 mm.

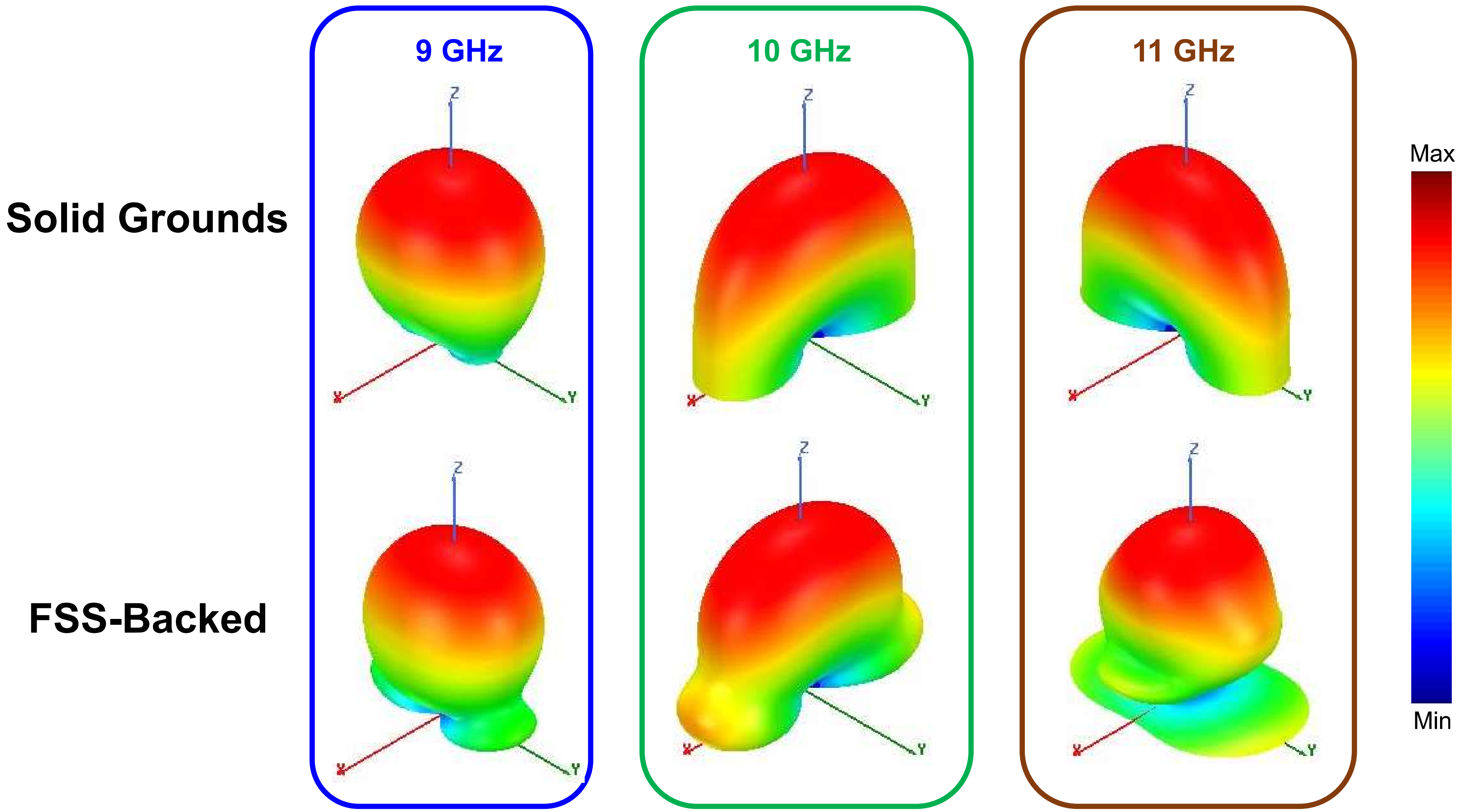




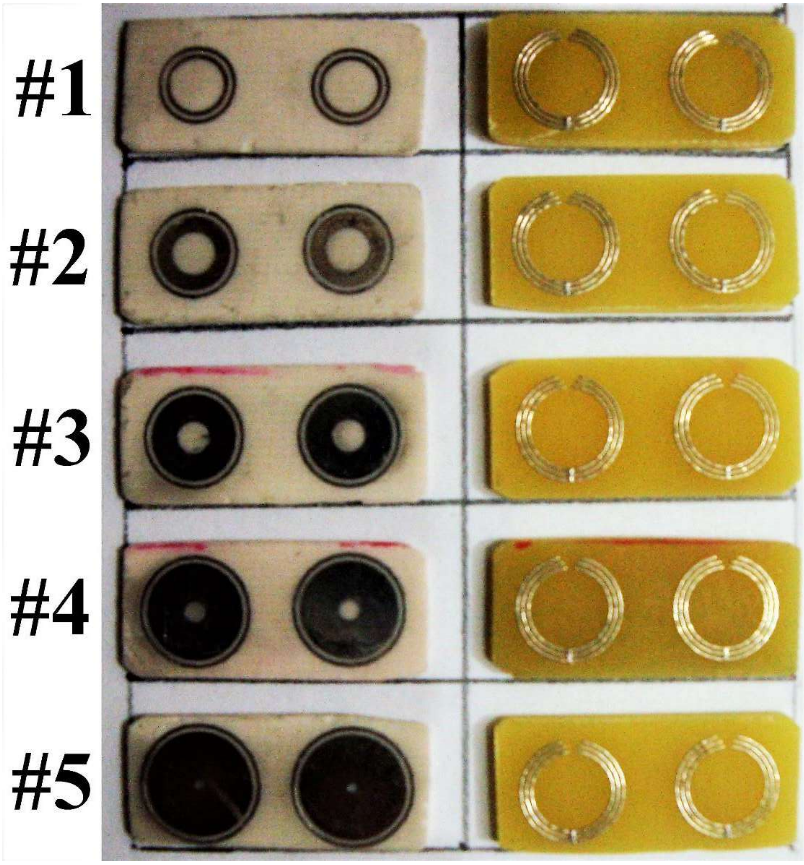
h_1 = 1.6 mm, h_2 = 0.8 mm



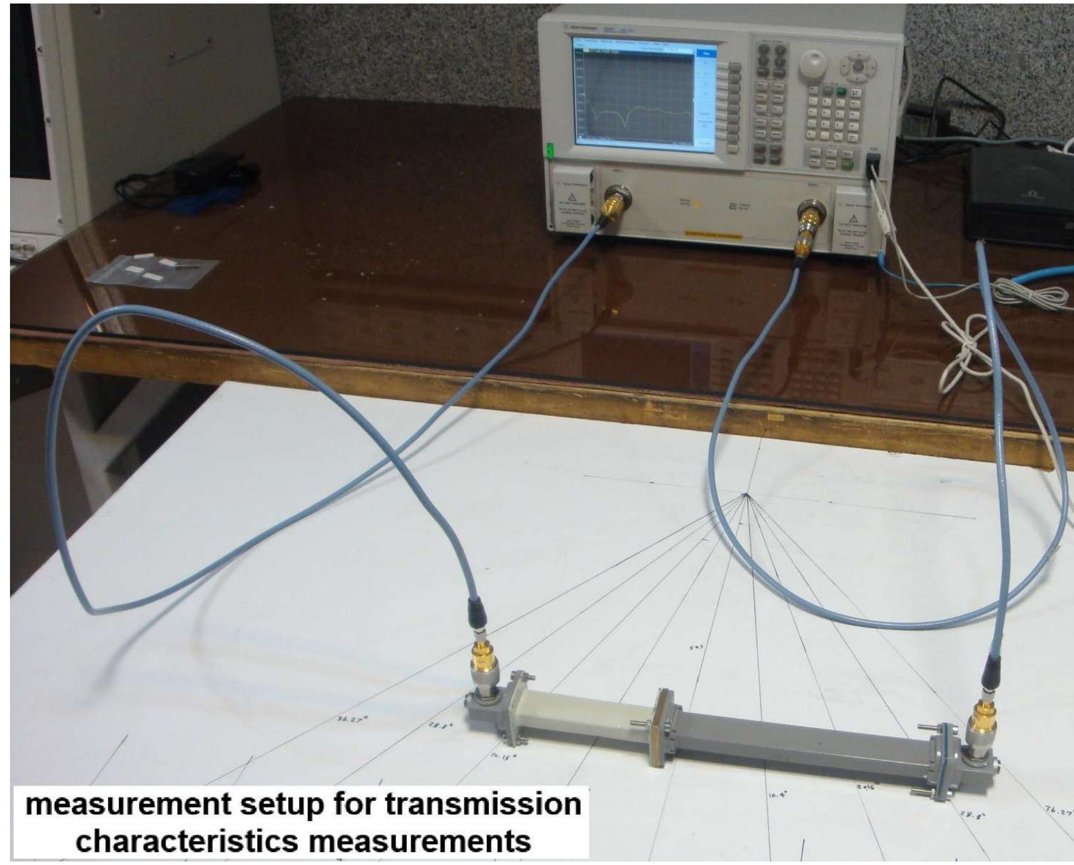
Element reflection properties at 10 GHz with solid and FSS grounds.



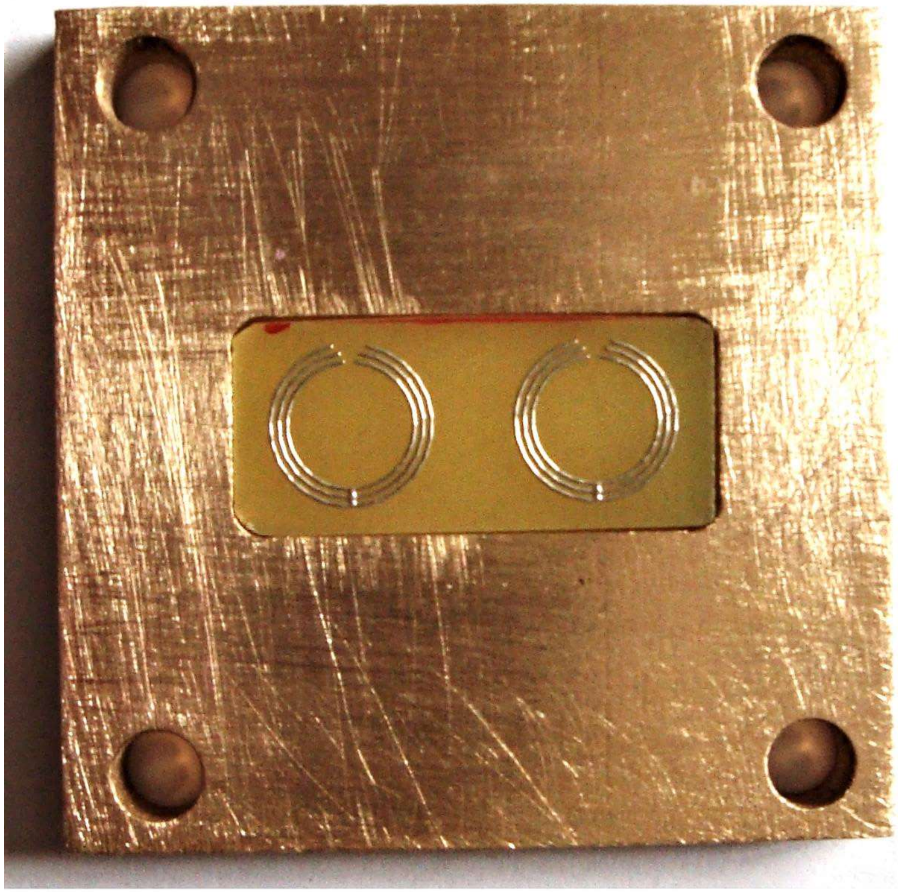
Normalized 3D pattern for element with D=7.7mm excited by a normal incident x-polarization plane wave.



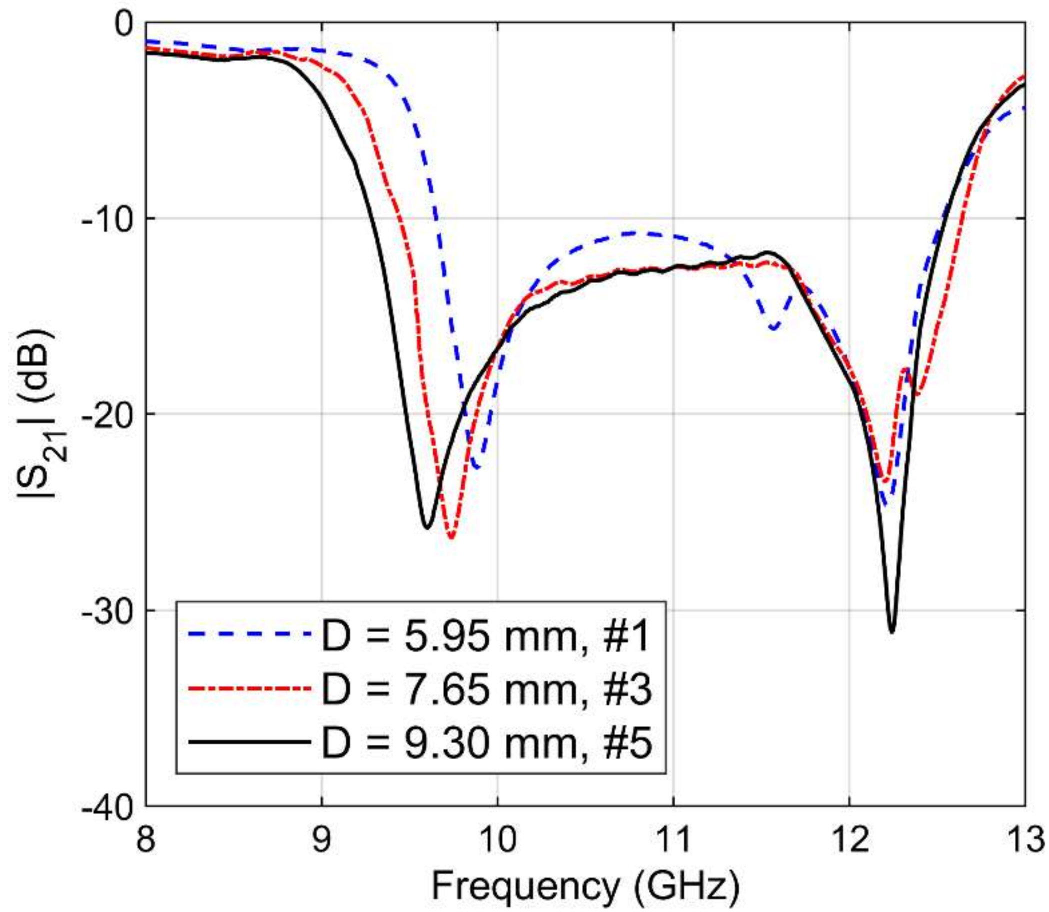
Prototypes of the fabricated unit elements



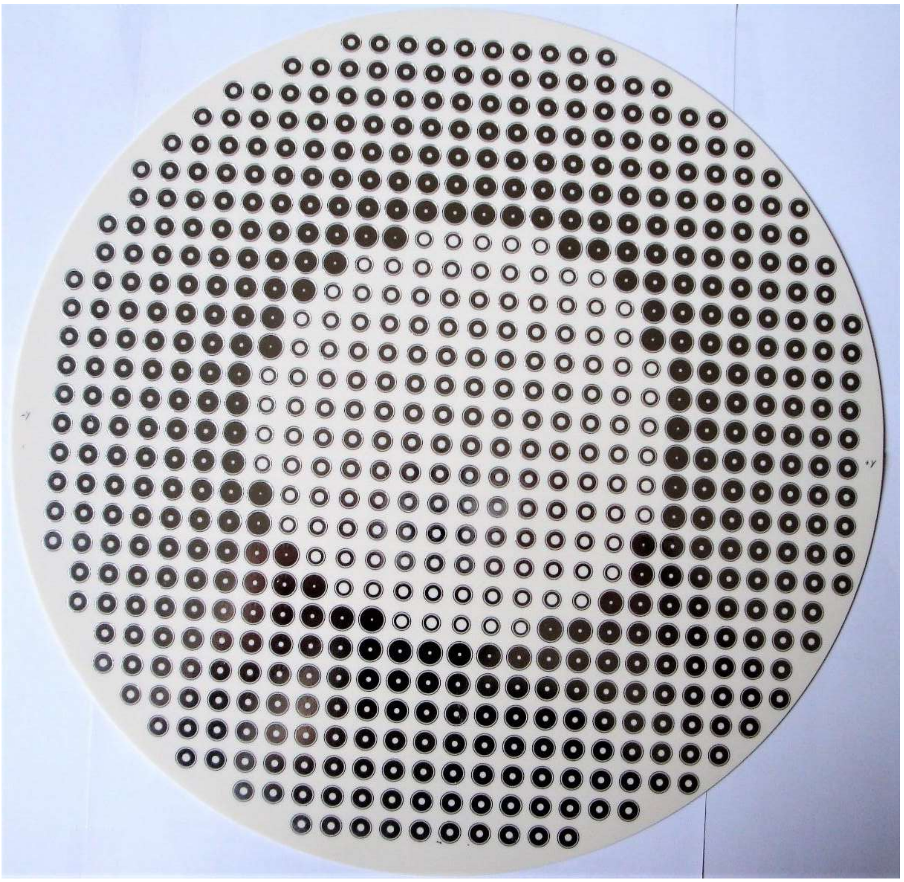
Waveguide measurement setup



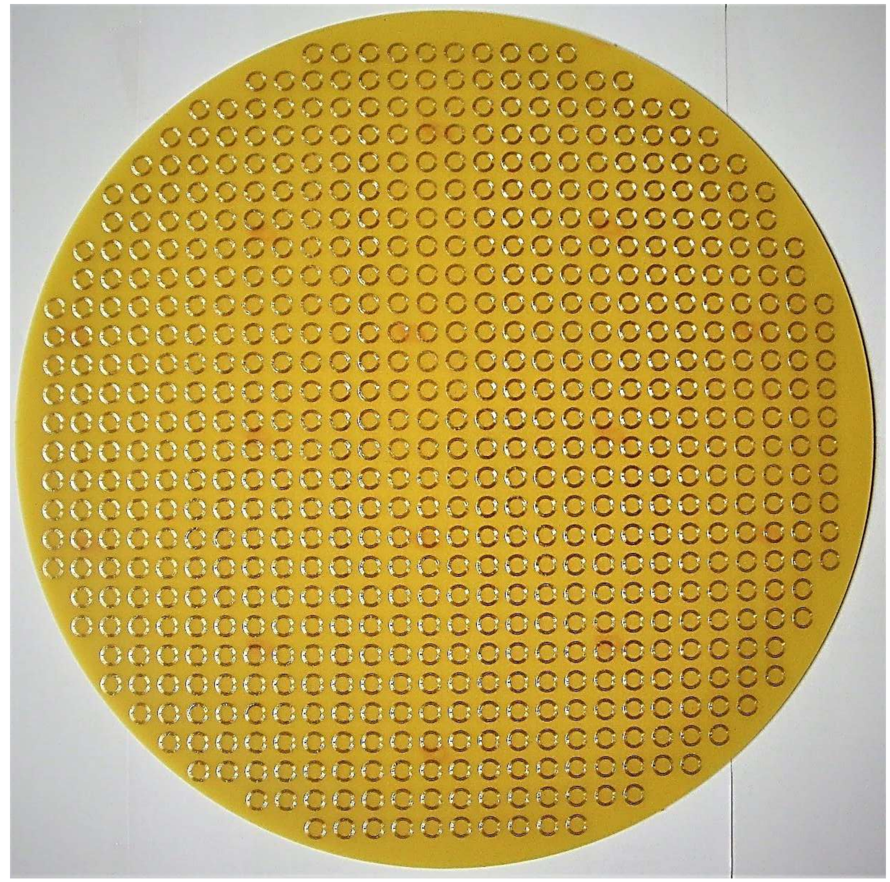
Sample holder



FSS-Backed Reflectarray Antenna

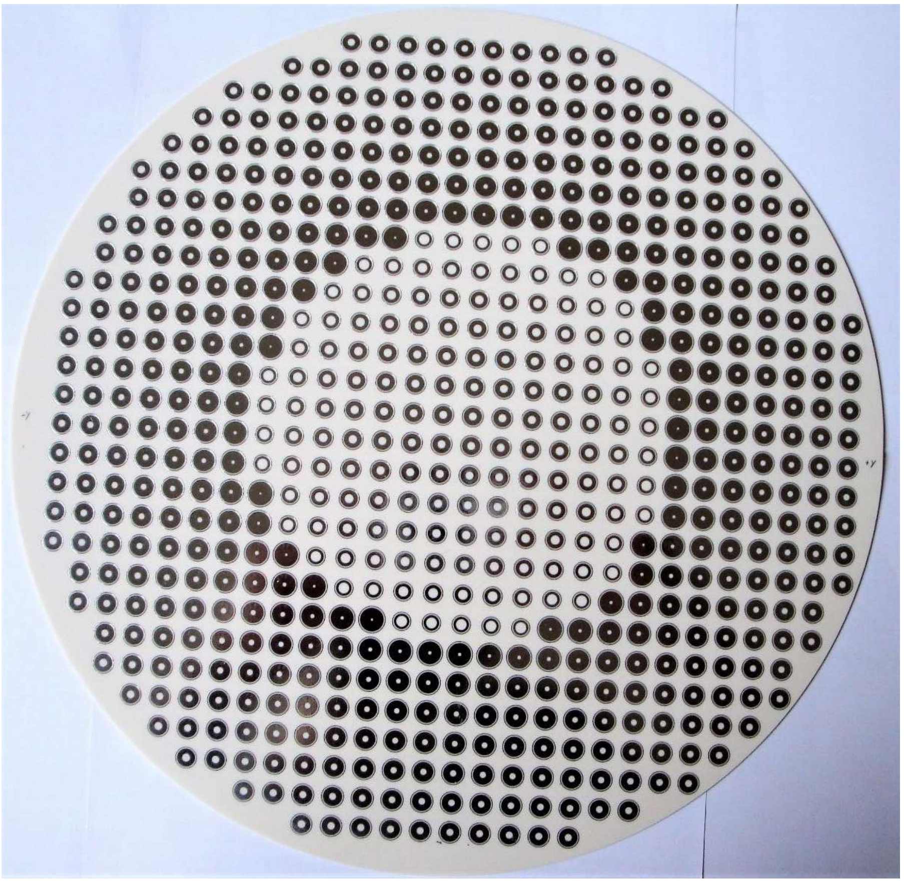


Unit Elements Layer

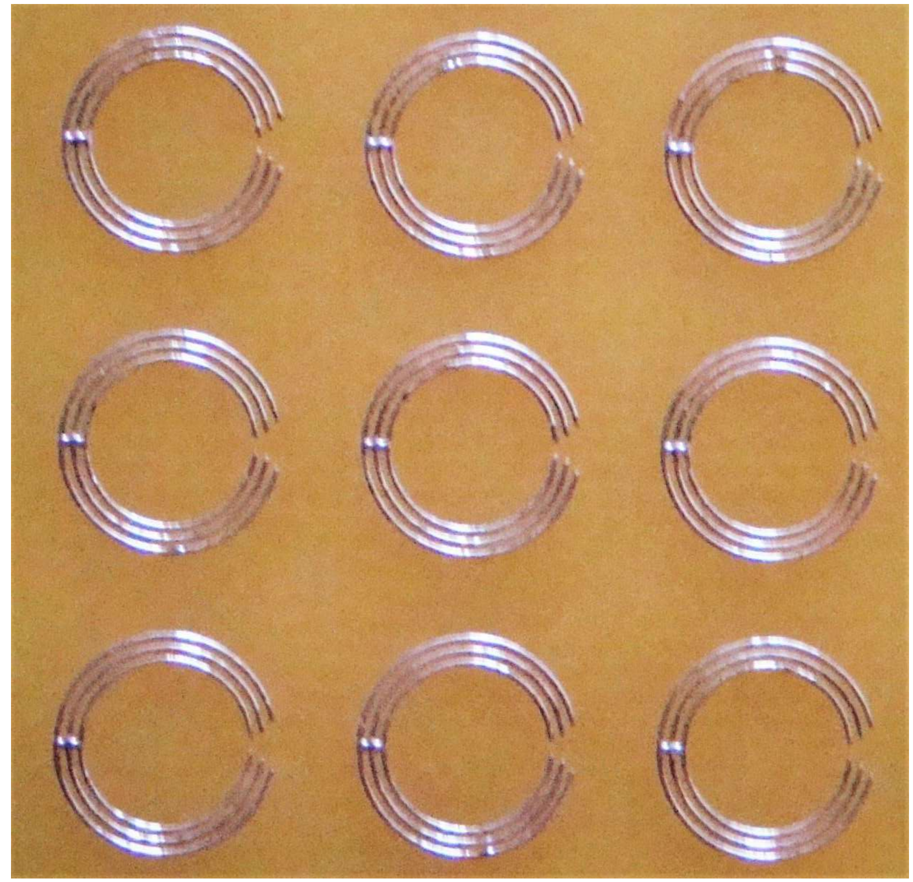


FSS-Backed Layer

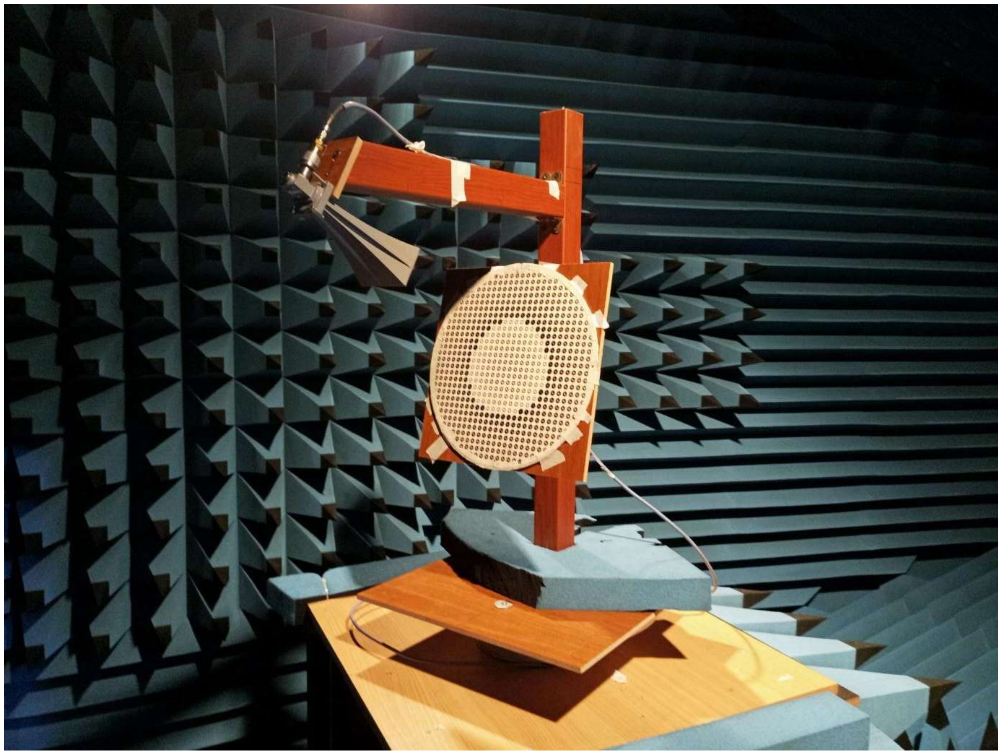
FSS-Backed Reflectarray Antenna



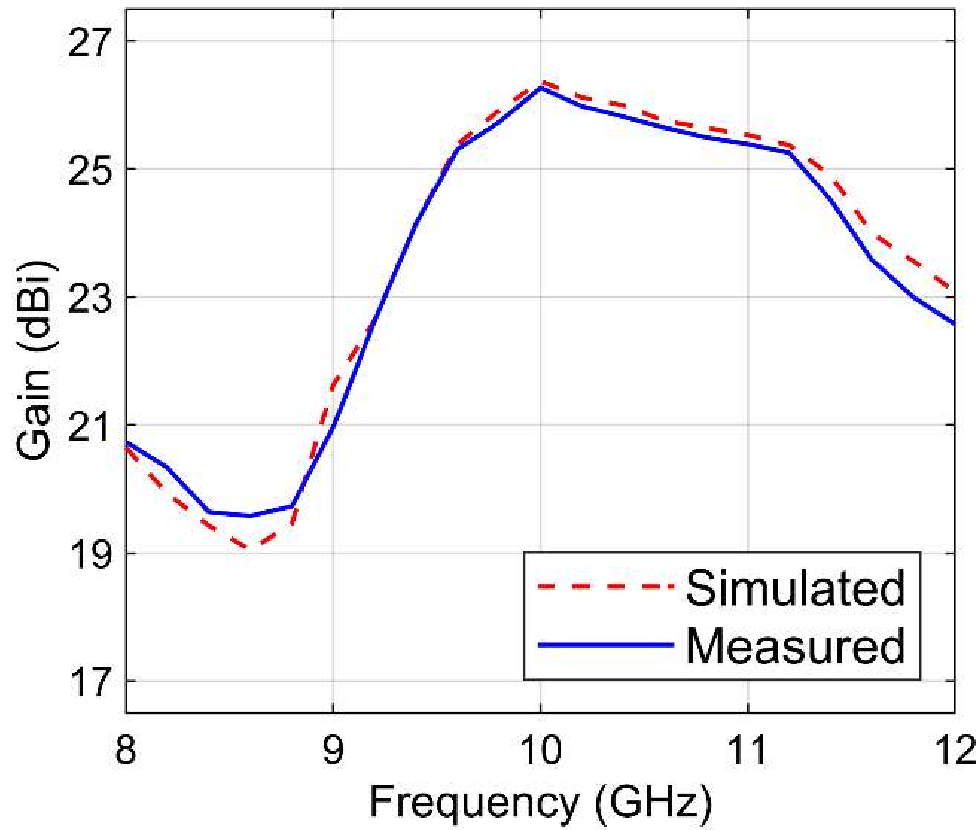
Unit Elements Layer



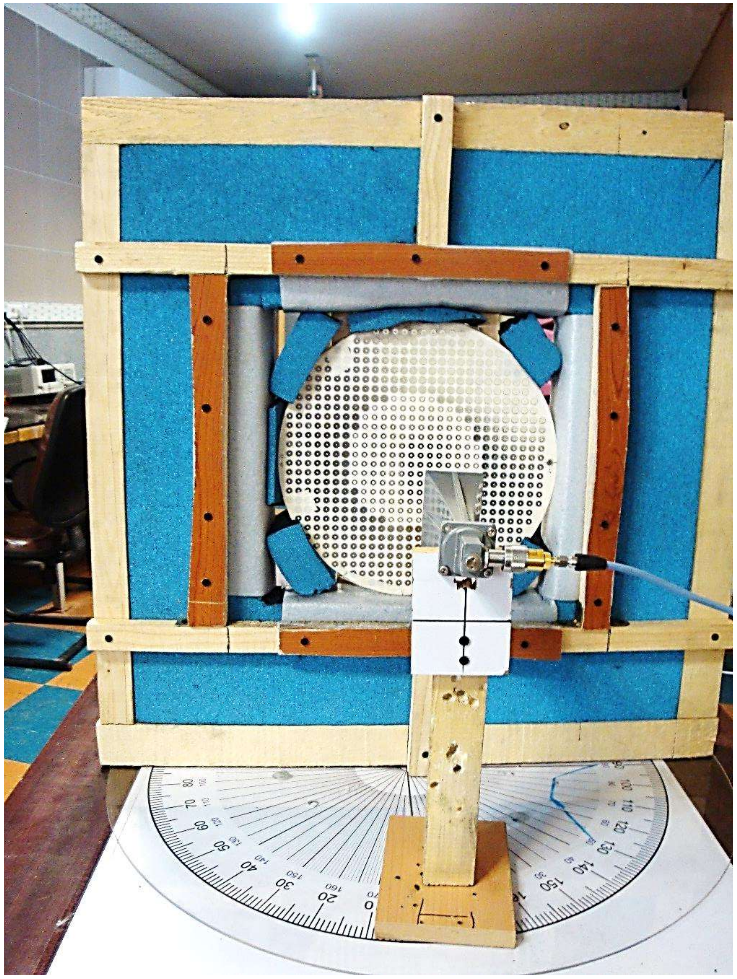
Close View of 3×3 FSS Unit Cells



FSS-backed antenna measurement setup

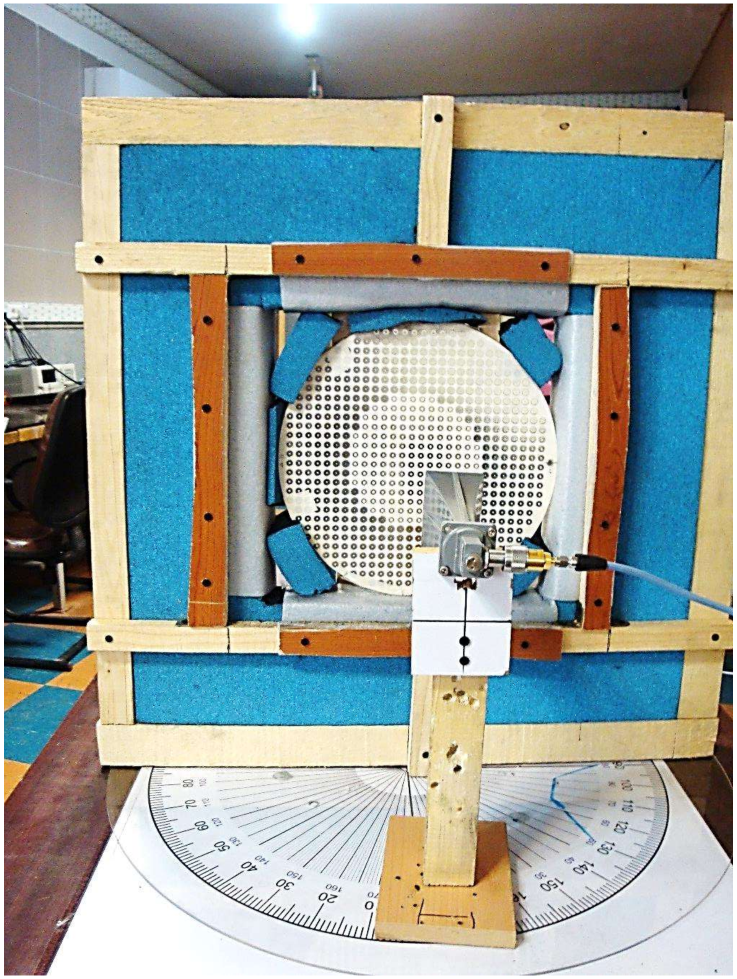


The gain and efficiency of the fabricated FSS-backed reflectarray antenna at **10GHz** are **26.26 dBi** and **44.87%,** respectively, and 1dB gain bandwidth is found to be equal to **15.4%**.

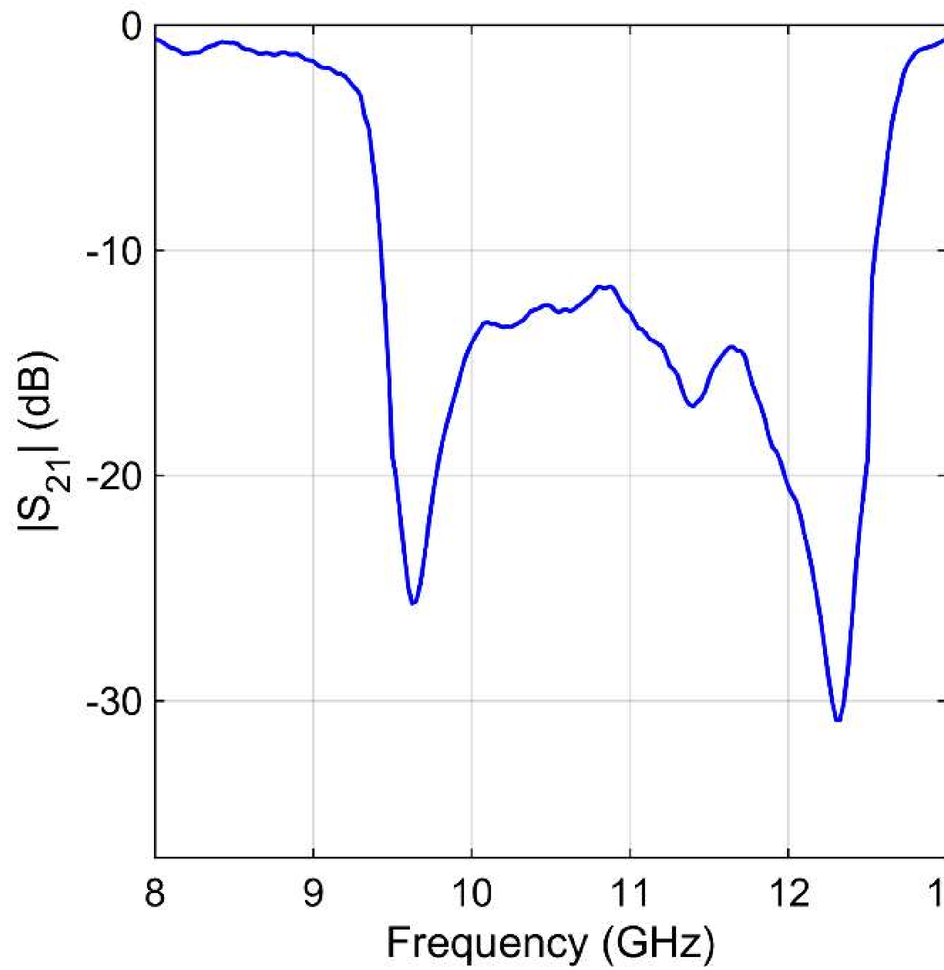


Free space measurement setup

Monostatic RCS reduction performance



Free space measurement setup



Monostatic RCS reduction performance

Conclusion

- An enhanced unit element was presented with a reduction in phase sensitivity to manufacturing inaccuracy, a reducing in the unit element losses and a high angularity for oblique incidence which resulted in a high-efficiency, wideband performance.

- To improve the gain bandwidth of antenna, the phase constant ($\psi_{\circ}$) value at the reflectarray aperture was gradually tuned. In comparison with the conventional antenna ($\psi_{\circ} = 0°$), the 1dB gain bandwidth showed a 43% improvement without no additional cost.

- The triple-connected split ring resonator as bandstop FSS was used in each unit element instead of the ground plane. The radar cross section (RCS) and cross-polarization levels of the presented FSS-backed RA antenna were considerably improved compared to solid ground reflectarray.

Publications

Journal Papers:

[1] J. Nourinia, Ch. Ghobadi, **B. Mohammadi**, F. Alizadeh, “Study of phase and patterns characteristics of a sub-wavelength broadband reflectarray unit element based on triple concentric circular-rings”, *Applied Computational Electromagnetics Society Journal (ACES)*, vol. 33, no. 6, pp. 714-717, 2018.

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[3] **B. Mohammadi**, J. Nourinia, Ch. Ghobadi, A. Mahmoud, M. Karamirad, F. Alizadeh, H. Mardani, “Enhanced reflectarray antenna using elements with reduced reflection phase sensitivity”, *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 7, pp. 1334-1338, 2018.

[4] **B. Mohammadi**, J. Nourinia, Ch. Ghobadi, M. Karamirad, F. Alizadeh, “Enhanced reflectarray antenna backed with sub-wavelength frequency selective surface ”, *IEEE Transactions on Antennas and Propagation*, Under Preparing.

Publications

IEEE-Index Conference Papers:

[1] **B. Mohammadi**, J. Nourinia, Ch. Ghobadi, I. Aryanian, "Analysis, design and fabrication of a reflectarray antenna using elements with reduced reflection phase sensitivity", 2018 9th International Symposium on Telecommunications (IST'2018), pp. 696-699, 2018. **(Best Paper)**

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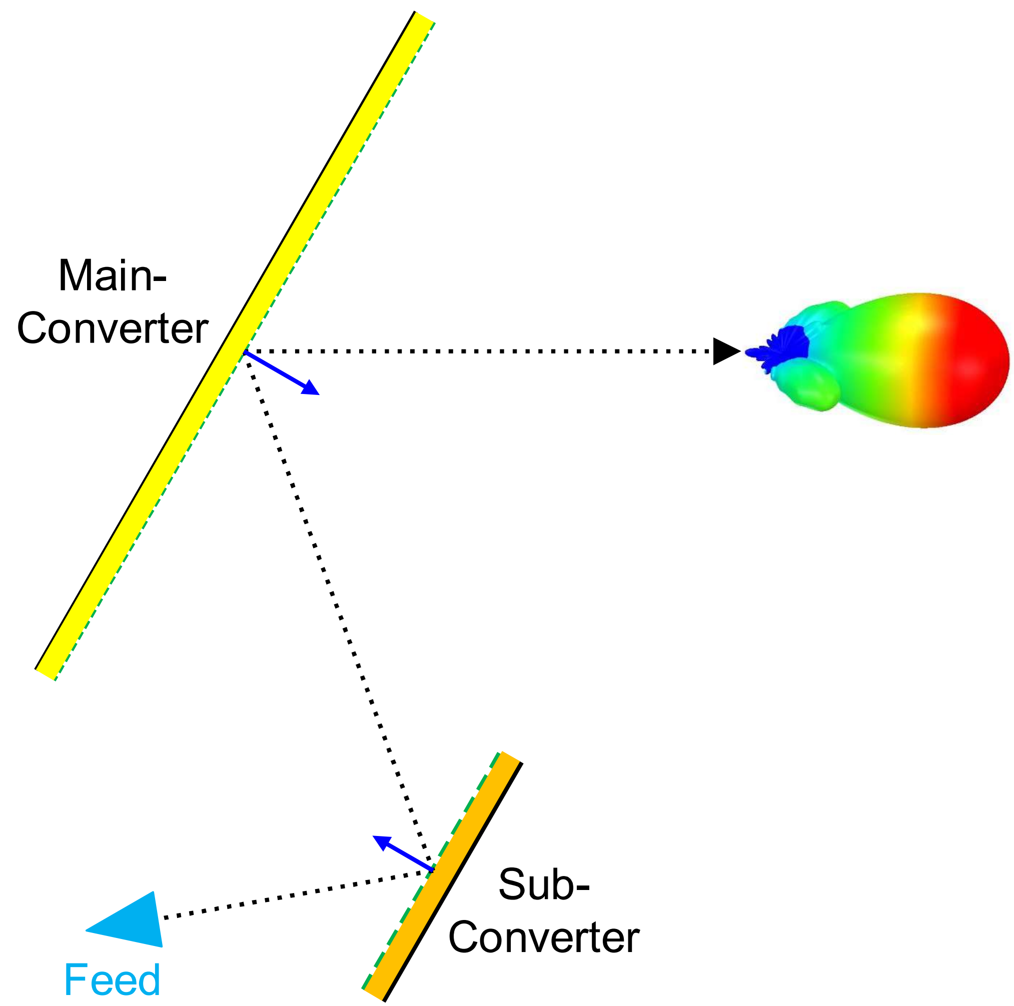
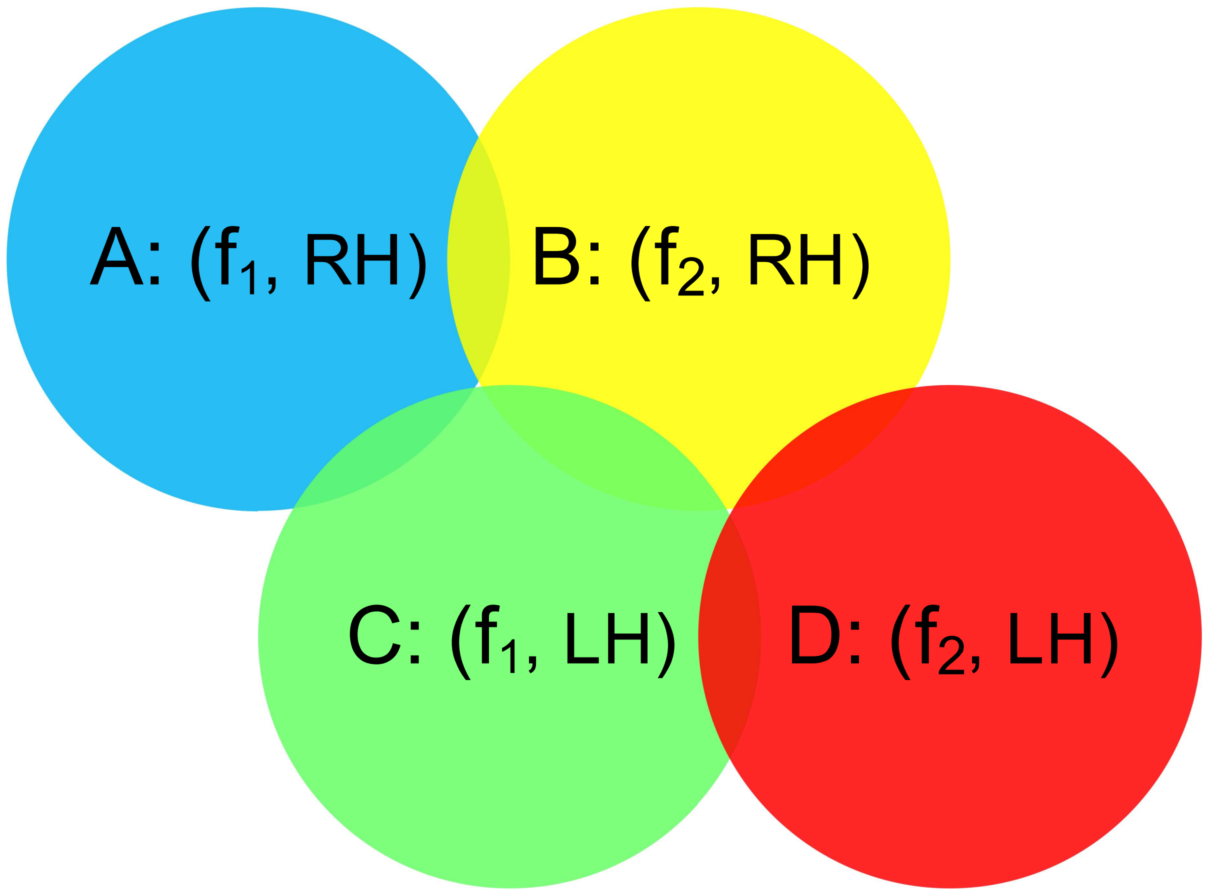
Future works: Dual-Converter Antenna



Multi-Beam, Multi-Band, Multi-Polarization



Thanks for your attention.

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Periodic Structures   Filters   Small Antennas   MIMO Antennas   Metamaterials

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